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The undersigned hereby certify that they have read and recommend to the Committee on Graduate Studies for acceptance a dissertation on "Investigation of Great Bear Lake Minerals with Appendix on A Microscopic Technique for the Determination of Opaque Minerals" submitted by B. E. Souch, B.Sc. in Mining Engineering, in partial fulfilment for the degree of M.Sc.

Edmonton, Alberta
April, 1933.

INVESTIGATION OF GREAT BEAR LAKE MINERALS

with APPENDIX on

A MICROSCOPIC TECHNIQUE FOR THE

DETERMINATION OF OPAQUE MINERALS

by

Bertram Elford Souch, B.Sc. (M.E.)

Department of Geology,
University of Alberta.
1933.

A THESIS

Submitted to the University of Alberta
in partial fulfilment of the requirements
for the degree of Master of Science.

Signature of Author

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PREFACE

At the beginning of the academic year 1932, Dr. J. A. Allan of the University of Alberta suggested, as a subject for a thesis, the application of a microscopic technique to the ores of Great Bear lake, for the identification of the minerals. The writer, pleased with the suggestion, commenced work immediately and "combed" fairly thoroughly the available literature with an endeavor to find the most convenient and satisfactory methods of microscopic technique which could be employed at the University of Alberta. The methods of preparing the specimens, of applying the reagents, and of applying physical tests which were used with fair success, are included in the appendix to this thesis.

In the investigation of Great Bear lake ores, particular attention was given to the determination of the minerals, their mode of occurrence and their age relationships. In the identification of the minerals, the determinative tables of M. N. Short of Harvard University were followed. These tables, which have firmly established a definite, rapid and simple method of determining unknown minerals, were published in Short's "Microscopic Determination of the Ore Minerals" in 1931.

The writer wishes to express his especial indebtedness to Dr. J. A. Allan, who kindly criticized the work as it progressed, to Dr. P. S. Warren for excellent suggestions regarding the arrangement of the work and to Dr. R. L. Rutherford for criticisms and material aid throughout.

The Mining Department kindly offered the use of their polishing wheels and photomicrographic equipment. Dr. A. E. Cameron gave many helpful suggestions regarding the photography.

The majority of the specimens studied were from a collection by Dr. A. E. Cameron and were loaned to the writer by the Department of Geology.

Frontispiece

PLATE I. INVESTIGATION OF GREAT BEAR LAKE MINERALS

U. of A. 1933

Radio-graph of a Pitchblende Breccia from La Bine Point. Enlarged about 4 X.

Frontispiece

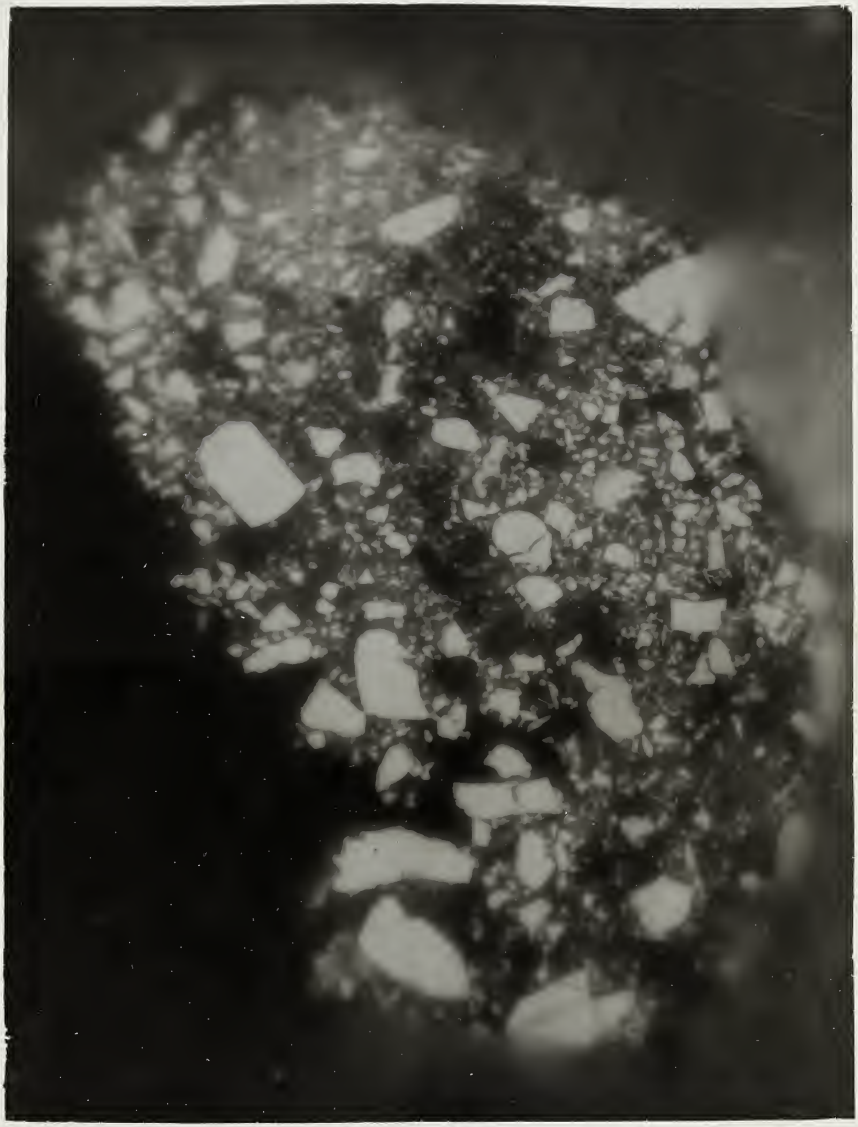


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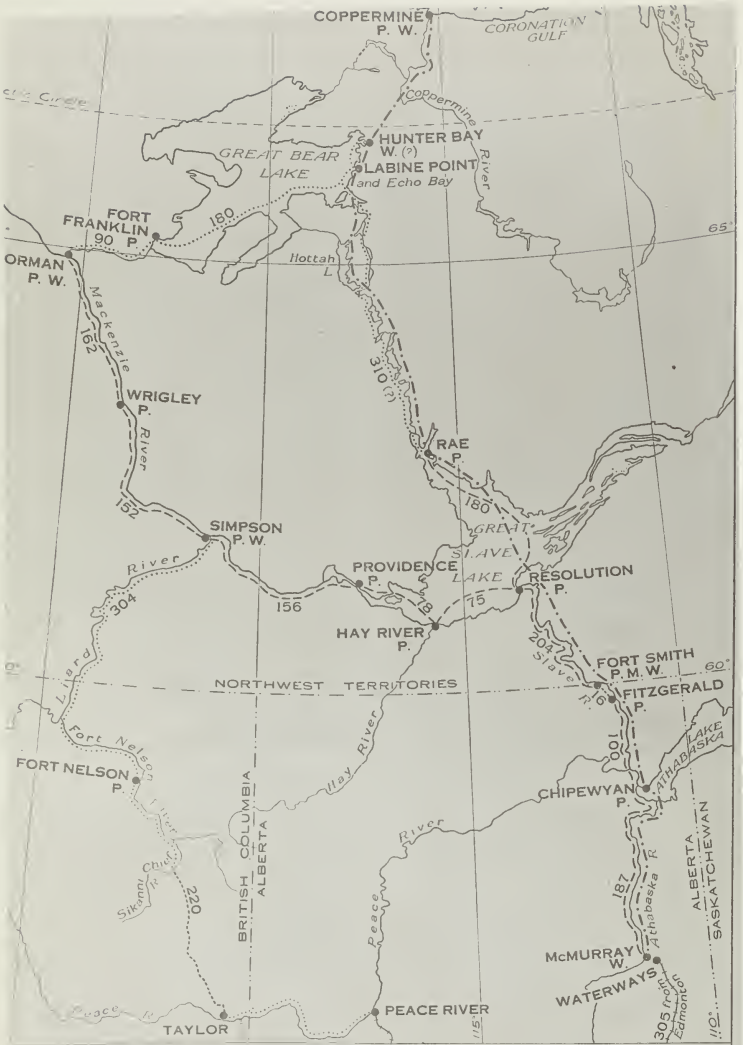
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INVESTIGATION OF GREAT BEAR LAKE MINERALS

B. E. Souch

University of Alberta
Department of Geology

1933



ROUTES TO

GREAT BEAR LAKE AND NORMAN

NORTHWEST TERRITORIES

Scale of Miles

100 50 0 100 200

— · — · — Main aircraft route
— — — Summer steamer route
..... Boat, scow, or canoe route
------- Portage
+++++ Railway
P. Trading post
M. Mining recording office
W. Wireless or telegraph
152 Approximate distance in miles between points

Geological Survey, Department of Mines, Canada. 1932.

Publication No. 2301

PLATE II. INVESTIGATION OF GREAT BEAR LAKE MINERALS

U. of A. 1933

PLATE II. TRANSVERSE SECTION OF UPPER PART OF STEM OF CYCAS

U. of A. 1938

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

INTRODUCTION.

The discovery in 1930 of a pitchblende-silver occurrence on Echo Bay in the Great Bear lake area has aroused keen public interest and because of its unique character on this continent, geologists are watching development with particular concern.

In 1931 representatives of small syndicates, as well as larger companies constituted a prospectors' rush into the area and many claims were staked within a few miles of the discovery on Echo Bay. In 1932 many more syndicates were formed and by August of that year about 200 traders, prospectors, geologists and mining engineers were in the area. The writer, employed by the Contact Lake Mining Company, was among these, spending about six months, beginning March 17, 1932, in the district. Having thus had an intimate knowledge of several of the mineral occurrences, it was thought profitable to study certain of the ores microscopically with an endeavour to determine their composition and

mineral relationships.

Great Bear lake lies partially within the Arctic circle and is about 150 miles east of the Mackenzie river. The pitchblende and silver discoveries are on the east shore in the vicinity of Echo Bay which is about thirty-five miles south of the Arctic circle. La Bine point on Echo Bay is about 900 miles north of McMurray by air route or 1400 miles from Waterways by water route via Mackenzie river, Fort Norman and Great Bear river. Boats can travel on Great Bear lake in August and September. Planes run from December till the latter part of March and from the latter part of June until September. The only means of communication with the outside world in other months is by wireless.

The mineralized area lies in the Coronation Mining Division in the District of Mackenzie, North West Territories. The office of the Mining Recorder for the district is located in the Administration Building at Fort Smith. Sub-mining recorders have been appointed and located at Resolution, Echo Bay, Simpson, Aklavik and Coronation.

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

GEOLOGY OF THE ECHO BAY AREA.

\- - -

PREVIOUS WORK.

As early as 1901 J.M. Bell(1) reported cobalt bloom on the east coast of Great Bear lake. In 1930 following the discovery of pitchblende and silver, C.W. Knight (2) investigated the geology of the Echo Bay Area. In 1931, J.P. Norrie(3) of the Dominion Explorers, G.G. Duncan(4) of the N.A.M.E., D.F. Kidd(6)(7) of the Canada Geological Survey and H.S. Spence(5)(8) of the Canada Mines Branch, published the results of their investigations in the area. In 1932 more detailed articles on the geology and mineralogy were published by D.F. Kidd (9)(14) J.A. Reed(10), H.S. Spence(11)(15)(19) Ellis Thompson(18), H.V. Ellsworth(17) and A.E. Cameron(12) (13)(16). In 1933 C. Palache and H. Berman(20) published the results of optical investigations of the oxidation products of pitchblende.

(1) Bell, J.M. - Report on the Topography and Geology of Great Bear Lake Geol.Surv., Can.-Ann.Rept.Vol.12, Pt.C; 1901.

(2) Knight, C.W. - Pitchblende at Great Bear Lake,-Can. Min.Jour. Oct.10, 1930, p.962.

(3) Norrie, J.P. - Prospecting and Exploration in the Great Bear Lake-Coppermine River area.-Bull.Can. Inst. Min.Met. Mar.1931,pp.349-362, also Trans. Can.Min.Met.,Vol.34-1931, p.110.

(4) Duncan, G.G. - Exploration in the Copermine River Area., N.W.T., Bull.Can.Inst.Min.Met., March 1931, pp.363-382, also Trans.Can.Inst.Min.Met.,Vol.34-1931.

(5) Spence, H.S. - Radium Bearing Minerals from Great Bear Lake. - Mines Branch, Dept.Mines Can.,Mem.Ser. No.48, March 1931 (included in (15)).

(6) Kidd, D.F. - Great Bear Lake-Coppermine River Area, Can.Inst.Min.Met.,Bull.No.245-1932.

(7) Kidd, D.F. - Great Bear Lake-Coppermine River Area, Mackenzie District, N.W.T.-Geol.Surv.Can.Sum.Rep. 1931, p.47.

(8) Spence, H.S. - Occurrence of Pitchblende and Silver Areas of Great Bear Lake, N.W.T. Mines Branch,Dept. Mines, Mem.Ser.No.51, Oct. 1931 (included in (15)).

(9) Kidd, D.F. - The Great Bear Lake-Coppermine River District. Can.Min.Jour., Jan. 1932, pp.5-12.

(10) Reid, J.A. - The Minerals of Great Bear Lake, Can. Min.Jour., Feb. 1932, pp.61-66.

(11) Spence, H.S. - Radium and Silver at Great Bear Lake, Met. Mar. 1932, pp.147-151.

(12) Cameron, A.E. - Geology at Echo Bay, Great Bear Lake, N.W.T., Northern Miner, Mar. 4, 1932.

(13) Cameron, A.E. - Geology of Echo Bay, Great Bear Lake, N.W.T., Presented to the Science Association of the University of Alberta, Mar. 17, 1932.

(14) Kidd, D.F. - A.Pitchblende-Silver Deposit Great Bear Lake, Can.-Ec.Geol.Vol. 27, No.2, Mar.-Apr.-1932, pp.145-159.

(15) Spence, H.S. - Character of the Pitchblende Ore from Great Bear Lake, N.W.T.-Can.Min.Jour.Vol.53,No.11, Nov. 1932.

(16) Cameron, A.E. - Mineral Development and Mining Possibilities, Great Bear Lake, N.W.T., Unpublished Lecture - Nov. 1932.

(17) Ellsworth, H.V. - Rare Element Minerals of Can., Geol.Surv.Can.-Ec.Geol.Ser.#2 - 1932.

(18) Thompson, Ellis - Mineralogy of the Eldorado Mine, Great Bear Lake, N.W.T.-University of Toronto Studies, Geological Ser.No.32 - 1932.

(19) Spence, H.S. - The Pitchblende and Silver Discoveries at Great Bear lake, North West Territories-Can. Mines Branch-Investigations of Mineral Resources and the Mining Industry, 1931 publ.1932 (Ref.Nos. 7 & 8 included).

(20) Palache, C. and Berman, H. - Oxidation products of pitchblende from Great Bear lake - American Mineralogist, Vol.18 - 1933.


GEOLOGICAL MAP
ECHO BAY AREA
GREAT BEAR LAKE N.W.T.
SCALE : 1 IN = 2 MI.
LEGEND
- Flat-lying dike
- Granite
- Granodiorite etc.
- Older Sediments & Volcanics.
Labine Pt.
C.M.& S. Co
Eldorado
Glacier Bay
Mystery
Echo
Bay
Dowdell Pt.
Bonanza
Bay
Contact Lake
R.E.M.R.
Vie
Gov't
Sur. Sta.

GENERAL GEOLOGY OF THE AREA.

- - -

In the area under consideration and shown on Plate III there are three main rock groups, all of which are probably Precambrian in Age. These, in descending chronological order, are:

Basic dykes and sills, and large quartz veins.
Granitic and related intrusives.
Folded sediments and volcanics.

The folded sediments and volcanics which are the most abundant rocks in the area, consist of tuffs, conglomerates, sandstones, quartzites, agglomerates, flows, sediments of volcanic origin, cherts, lean iron formation, limestone and dolomite. This rock group extends for six miles south and forty miles north of the pitchblende and silver deposits.

The southern part of this exposure is shown in contact with granitic and other intrusive rocks on the accompanying map, Plate III.

The intruding rocks are granitic, granodioritic and syenitic masses which although here grouped together are probably of more than one age. These rocks are found

twenty miles north of the deposits fringing the islands on the east coast. A southern contact is shown on the accompanying map.

Numerous diabase dykes with almost vertical attitude cut all the rocks in the area. Their average width is about 100 feet. Flat lying dykes cutting across the older formations are prominent in the vicinity of Cameron Bay, Glacier Bay and the east end of the South West Arm of Echo Bay.

The large quartz veins which in places attain a width of over 200 feet cut all the rocks in the area with the exception in several cases where diabase dykes cut across it. In other instances the quartz veins cut through diabase.

Flat lying sandstones and conglomerates younger than the granite but older than the dykes are found at a distance of forty miles north of Echo Bay and extend north and west from here. These may possibly be correlated with the Coppermine River series.

GEOLOGY OF THE MINERAL DEPOSITS.

\- - -

To date three types of mineral deposits have been

found in the Echo Bay area: Pitchblende and silver deposits, silver deposits, and gold deposits. Of these the first two are by far the most extensive. Gold has not as yet been found in profitable quantities.

PITCHBLENDE AND SILVER DEPOSITS

Several occurrences of pitchblende and silver have been reported and two of these are being mined. These are on La Bine Point on claims owned by the Eldorado Mining Co. and on the centre north shore of Contact Lake on claims now worked by the Bear Exploration and Radium Mining Co. A third occurrence which proves to be of great geological interest is on the Thompson claims off the south west shore of Contact Lake. No mining has been done on these claims to date.

LA BINE POINT: La Bine Point is the site of the original discovery and has received the most study and development.

The ore bodies occur in three large fracture zones several hundred feet apart and which strike in a general east north-east direction. They lie in the older sedimentary and volcanic series which are highly altered by the granitic intrusive which outcrops nearby in several places along the shore. In many places the older formation contains zones which are heavily charged with either

magnetite or pyrite and in many places with both minerals, and give rise, through weathering to large yellow gossan outcrops.

Number one mineral zone is the original discovery and is the southernmost ore body. It can be traced for over 2000 feet, up over a high hill and is lost for a time in a drift covering, but is probably more or less continuous into the C.M. & S. property where it occurs as numerous shear zones.

Number two zone has received the most development to date. It strikes sub-parallel to Number one zone and mineralogically it is more persistent although it has not been traced for so great a distance.

In zones number one and two, the mineralogy is very complex. Spence (19) gives four vein types which make up the ore bodies:

1. Pitchblende - quartz veins. The quartz is brownish in color and is locally replaced by carbonates with which are associated sulphides, arsenides and native silver.

2. Silver - carbonate veins. The richer silver ore is from this type of vein. The carbonate is principally rhodochrosite.

3. Silver - Cobalt - Carbonate - veins. The silver chiefly occurs in dendritic habit in a carbonate gangue. Argentite is sometimes also present.

4. Cobalt - bismuth - quartz veins. The cobalt is in the form of arsenides with smaller amounts of nickel. Bismuth as native metal is found commonly as a center in dendrites of other minerals.

Number three zone has not received much development work and so far only pitchblende and quartz in significant amounts have been reported. This zone lies several hundred feet north of the Number two zone and strikes sub-parallel to it, probably converging towards it to a slight extent.

"M" GROUP ON CONTACT LAKE: Development work began on this property in 1932 by the B.E.A.R. Company. Of the several silver and pitchblende showings owned by this company, development work has so far been confined to the "M" group on the center north shore of Contact Lake about one-half mile from the water's edge.

The veins occur in a zone of fracturing and shearing which strikes N.E. with a steep dip to the S.W. These veins which are from 1½ to 3 or 4 feet wide cut across a massive diorite, which when followed south to Contact Lake appears to grade into pink granite. Copper sulphides are persistent throughout the ore body, but so far the pitchblende and silver appear to be in lenses. Leaf silver in joints in the hanging wall of the pitchblende lens is common. Where the silver ore is richest

it is in a carbonate gangue. The mineralization is very similar to the Eldorado ore bodies.

THOMPSON GROUP, BOW LAKE: These claims were staked by White and McKee in 1932. Here, a deposit of pitchblende, silver and gold in a diabase dyke is probably the most outstanding mineral occurrence in the area. The vein, of which the walls are very indefinite, can be followed diagonally across the diabase for some 200 feet and into the granite for several feet on either side. The pitchblende, silver and gold were found in a small branch vein of the main quartz lead. Chalcopyrite and pyrite are abundant throughout in a gangue of quartz and various iron and calcium bearing carbonates. The striking similarity of this occurrence with that of the Eldorado and B.E.A.R. properties brings up a very interesting point as regards the genesis of the deposits. The strike of the dyke is roughly east-west and the strike of the vein is about N70°W.

SILVER DEPOSITS.

Several silver occurrences which may prove of economic significance have received considerable attention and these will be discussed separately below.

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

ECHO BAY GROUP, LA BINE POINT: In 1930 the Consolidated Mining and Smelting Company staked this group of claims which adjoin the Eldorado on the north-east. Here, there are a number of shear zones in a belt about 300 feet wide and over a length of 2000 feet, which occur in the old altered sedimentary and volcanic series. They consist usually of a band up to a foot wide, of intense shearing and alteration with considerable fractured rock on either side. Of the silver minerals argentite and native silver are important. Some pitchblende has been found. Mineralogically the property resembles the Eldorado.

BONANZA CLAIMS,-DOWDELL POINT: These claims which are about six miles south of La Bine Point were staked in 1931 by La Bine and St. Paul and are property of the Eldorado Company. At two places about one-half a mile apart spectacular silver ore was discovered in tabular shaped ore bodies which lie in fractured zones in a narrow belt of the old sedimentary series. On the south these rocks are in contact with granite and on the north with a more diortic type of rock. The silver is native and is in a carbonate gangue. Development work is in progress on these claims.

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

CAMSELL RIVER CLAIMS: These claims are on the north bank of the Camsell river, about 9 miles from its mouth at Conjurer Bay. Silver was found in 1932 in shear zones in the old porphyry series at several localities. On the AX. group of claims, massive silver is found in a cabonate gangue with native bismuth and some of the cobalt group of minerals. Silver is also found on property staked by J. D. Nickelson and on the How group. The granite outcrops less than a mile from the deposits.

VIE GROUP, CONTACT LAKE: These claims lie east of the "M" claims which have been described above. They were staked by the Contact Lake Mining Company in 1931, and in 1932 small amounts of silver were found. The rocks of the group are highly altered sedimentary and volcanic rocks of the older series and they are intruded by granite, the contact of which lies within the claims along the shore of Contact Lake. Trenching on No. 1 vein on Vie. 2 reveals a complex siliceous ore body which strikes roughly east-west. The vein occupies a shattered zone in which considerable shearing has taken place and has given rise to chloritic schists on both the hanging wall and the foot wall. The ore is complex. The minerals include the arsenides and sulph-arsenides of cobalt and nickel with considerable native bismuth.

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

GOLD DEPOSITS.

Although gold has been reported from several properties at different times, this metal has not yet gained a prominent place in the Great Bear lake mineral field. Visible gold has been found on the Oro claims north of La Bine point. Here it occurs in a branch vein of a quartz lead which is about one foot wide. Gold is also reported on some of the Camsell river properties. The Eldorado, the North West Radium Minerals, Lt'd., and the Bear Exploration and Radium companies report gold in their assays.

POSSIBLE SOURCE OF THE MINERALIZATION.

Since 1930, at which time C. W. Knight reported two intrusives in the Echo Bay, one a plutonic granitic intrusive and the other a "basic intrusive sill", there has been considerable doubt as to which of these was responsible for the deposition of the ore-bodies.

The "basic intrusive sill" reported by Knight has since been shown to closely resemble diabase(x) and is probably a flat lying dyke rather than a sill. It outcrops on La Bine Point. The silver occurrences of the

Consolidated Mining & Smelting Co. are above it and several of the Eldorado Ore bodies are hypothetically below it. The granite outcrops very near to both properties.

With the exception of the Thompson ore body, the fracture zones containing the deposits diminish in width away from the granite contact(xx) and usually within a distance of a few hundred feet they are reduced to minor shear zones. The granitic intrusive was no doubt responsible for these fractures which at this time were filled, partially at least with quartz, carrying copper and other sulphides. Later when the diabase intruded, these fractures were re-opened allowing a duct along which mineral laden solutions from the diabase, could travel. Such a process may have been repeated more than once, giving rise to the complex nature of the ore.

In this regard, however, before definite conclusions can be drawn, several problems must be solved: Has there been more than one acid plutonic intrusion? Are the diabase and quartz dykes and the "granite", different phases of the same intrusive, and if so, how can

(x) Lowther, G.K. - Unpbl'd Mss. - Thesis U.of A. 1933.

(xx) Granite used in this sense, also includes syenite and diorite, etc.

the fact that diabase dykes cut a younger series of rocks which rest uncomformably on the granite, be accounted for? How often did diabase intrude? Is the so-called "diabase sill" really a sill or is it a flat lying dyke? With these questions unsolved it is difficult to state the genesis of the ore-bodies. In consideration of the pitch-blende-silver occurrence in diabase on the Thompson Group of claims, however, the writer is of the opinion that the intrusive which gave rise to the diabase was also responsible for the deposition of the ore bodies.

MICROSCOPIC INVESTIGATION OF THE MINERALS.

\- - -

LIST OF METALLIC MINERALS.

Some forty metallic minerals have been identified in the ore bodies of Great Bear Lake. Of these the writer has identified twenty-six. Below they are listed, as far as possible in the order of their deposition:

(1) Pitchblende, (2) Lead, (3) Arsenopyrite, (4) Pyrite, (5) Tetrahedrite, (6) Tennantite, (7) Sphalerite, (8) Pyrrhotite, (9) Hematite, (10) Magnetite, (11) Bornite, (12) Chalcocite, (13) Chalcopyrite, (14) Galena, (15) Niccolite, (16) Chloanthite, (17) Smalltite, (18) Cobaltite, (19) Skutterudite, (20) Rammelsbergite, (21) Safflorite, (22) Baumhauerite, (23) Native Bismuth, (24) Argentite, (25) Pyrargyrite, (26) Covellite, (27) Native Copper, (28) Native Silver, (29) Gold, (30) Limonite, (31) Manganite, (32) Psilomelane, (33) Mineral X,(x), (34) Uranophane, (35) Zippeite, (36) Mineral Y(x), (37) Azurite, (38) Malachite, (39) Annabergite, (40) Ethyrite.

(x) Oxidation products of pitchblende described under Uranium minerals.

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

MODE OF OCCURRENCE OF THE MINERALS.

PITCHBLENDE - This uranium bearing mineral can be recognized in three forms; as colloform masses, as angular fragments in a quartz and carbonate matrix, and as curving veins. All three forms are traversed by numerous cracks which have been filled by later metallic and non metallic minerals. Chalcopyrite appears to be associated with it most frequently although tetrahedrite, bornite, covellite, the cobalt-nickel minerals and native silver of the metallic minerals have been found filling the cracks.

LEAD - has been identified by Kidd(14) in association with pitchblende from which it was probably derived by radioactive disintegration.

ARESNOPYRITE - This mineral was not recognized in any of the specimens examined by the writer but has been reported by Ellis Thompson(18) and D. F. Kidd(14) as occurring in small amounts in crystals of prismatic habit lining fracture cracks, and associated intimately with pyrite, chalcopyrite, tetrahedrite and native silver.

PYRITE - is present in a large number of the specimens studied. It is most commonly found with chalcopyrite with which it is often seen disseminated throughout

the altered wall rock. Asenopyrite is sometimes associated with it as mentioned above.

TETRAHEDRITE - is apparently most commonly found associated with chalcopyrite in a gangue of carbonates. In this association the chalcopyrite is the later mineral of the two metallics, being sometimes seen crossing tetrahedrite in minute veinlets. Tetrahedrite is also found as a central core in the cobalt and nickel minerals. Here it often forms remarkable cubes which are probably the crystal form of the earlier cobalt-nickel minerals. From the latter occurrence it is difficult to state the relative ages. Thompson has reported tetrahedrite as occurring in fairly intimate association with native silver and argentite. It is quite possible tetrahedrite deposition has occurred at more than one time.

TENNANTITE - is reported by Dr. H. J. Fraser of Harvard University in a report by Spence(19). It is associated with a carbonate gangue.

SPHALERITE - occurs usually as irregular blebs in association with galena and chalcopyrite. It appears younger than either of these. Ellis Thompson(18) reports sphalerite as occurring in massive form and associated with bornite, chalcocite, tetrahedrite and skutterudite.

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

PYRRHOTITE - A mineral giving the characteristic etch reactions of pyrrhotite was found in one section. Here it was intimately associated with chalcopyrite and pyrite and appeared to be simultaneous in origin with these.

HEMATITE - was found in several specimens associated with quartz. Its relation to the other minerals is not known since it was not found in direct contact with them.

MAGNETITE - occurs as scattered crystals in a quartz gangue. Thompson reports magnetite being cut by later quartz stringers which carry sphalerite, chalcopyrite and pyrite.

BORNITE - has been seen in several specimens. It commonly occurs as a bladed intergrowth in chalcopyrite. It occurs as a graphic intergrowth with chalcocite. It has been seen in the massive form in association with chalcocite, covellite, sphalerite, and tetrahedrite. Thompson(18) shows this association. Probably its most common occurrence is as graphic intergrowths with chalcocite.

CHALCOCITE - occurs in much the same manner as bornite, but it was observed in several instances along with chalcopyrite filling cracks in the pitchblende. Chalcocite is placed here because of its intergrowth with

bornite; probably much of it is supergene in origin.

CHALCOPYRITE.- is probably the most abundant metallic mineral and probably represents several stages of deposition. It is found with quartz in cracks in the pitchblende. It is seen in intimate association with tetrahedrite and carbonate gangue, the whole being enclosed by concentric shells of cobalt-nickel minerals. It is found as mentioned above, with chalcocite, the latter sometimes altered to covellite. It is found with bornite as an intergrowth and in a massive form associated with pyrite. It is often seen disseminated in the altered wall rock, and throughout the quartz and carbonate gangue. Other occurrences have been noted above and will be noted below.

GALENA - is found as a crystalline aggregate with massive chalcopyrite, bornite and covellite. This mineral has been observed in a number of specimens from the Camsell River area. Kidd(14) reports it in cracks in pitchblende with tetrahedrite, chalcopyrite, bornite and other minerals. At La Bine Point the common associated minerals seem to be tetrahedrite, galena and sphalerite.

NICCOLITE - Specimens containing niccolite were studied from the Vie 2 claims on Contact lake. Here

it occurs as a central core in vugs in wall rock surrounded by a concentric shell of cobalt-nickel minerals. Commonly in the centre of the niccolite are cavities which are lined with a green nickel arsenate (Annabergite). The niccolite is also found disseminated in small amounts through the wall rock and gangue.

CHLOANTHITE - occurs as a concentric shell around the niccolite in specimens from the Vie 2 claims. On the one side it grades into the niccolite with no definitely sharp boundary, on the other it changes to a mineral which gives slightly different etch reactions and probably is smaltite.. Specimens from Glacier Bay contain chloanthite and skutterudite in zoned crystals and with minor amounts of smalltite having a core of tetrahedrite, chalcopyrite, quartz and carbonates and usually containing native bismuth.

SMALTITE.-- the modes of occurrence of this mineral as zoned crystals have been given under chloanthite.

COBALTITE - frequently occurs as one of the zones in the cobalt-nickel series. It has also been found in direct association with niccolite, bismuth and silver. In this association, the silver is later (cutting across it in places). When the cobaltite occurs as a zoned arrangement with other minerals of this group it is usually

very narrow and has its place between skutterudite and the chloanthite-smaltite series.

SKUTTERUDITE - occurs as zoned crystals with the cobalt nickel series as noted before. Thompson reports this mineral as isolated remnants of crystals of cubic habit associated chiefly with the common metallic minerals such as pitchblende, chalcopyrite, and native silver, and to a lesser extent with chalcocite, bornite, covellite, tetrahedrite, and sphalerite. It has been found as individual crystals associated with native bismuth.

RAMMELSBERGITE - was not determined or recognized by the writer but its occurrence has been reported by Thompson(18). He states it to occur generally in a massive aggregate of crystals of prismatic habit which are associated with the cubic arsenides; skutterudite, smaltite and chloanthite. Occasionally also a few isolated crystals of rammelsbergite are found in association with metallic minerals such as pitchblende, chalcopyrite, native silver and tetrahedrite.

SAFFLORITE - was not recognized by the writer but is reported by Thompson(18). He identified it as occurring in two specimens with rammelsbergite.

BAUMHAUERITE - has been reported by Dr. H. J. Fraser, in a report by Spence(19).

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

NATIVE BISMUTH - is very widespread but in no place is it found in large quantities, possibly with the exception of Vie 2 Group where fairly massive bismuth occurs in a gangue of quartz and calcite and some rhodochrosite. Here it is seen also to occupy a central position surrounded by minerals of the cobalt-nickel group. The bismuth is later than the latter. In some specimens the bismuth is in vein-like forms, cutting these hard minerals and at other times it is seen partially surrounded by them. An interesting association of native bismuth, native silver and cobaltite and a mineral resembling niccolite was observed on specimens from the AX property on Camsell river. The silver and bismuth are later than the others.

ARGENTITE - has been observed under the microscope by Kidd(14) who reports it as occurring with covellite, tetrahedrite and galena. Thompson observed it as small inclusions in the larger areas of native silver. He reports it in one instance as being replaced by pyrargyrite.

PYRARGYRITE - occurs with argentite as noted under this mineral.

COVELLITE - was observed in several specimens associated with bornite, chalcopyrite, and chalcocite. In

one or two instances it was observed with tetrahedrite. Its other associations have been reported in preceding paragraphs.

NATIVE COPPER - has been observed by Kidd(12) in tiny specks in specimens from La Bine Point, its mineral relationships are not known.

NATIVE SILVER - occurs as a mass of wires, as plates and as leaves. Under the microscope these appear dendritic and fernlike in character. The richer silver ores are often quite barren of other metallic minerals. Where in large quantities it is associated with rhodochrosite and calcite. It has been seen also in a quartz gangue in smaller quantities. It is most commonly associated with galena, chalcopyrite and bismuth of the metallics. It has been observed with these in cracks in pitchblende.

GOLD - as native metal has been found in small amounts in quartz veins. It was not identified by the writer and its relations are unknown.

LIMONITE - is reported by Thompson as occurring in the fracture cracks, in one section, associated with manganite and native silver.

MANGANITE - was identified in several specimens from property between Government survey stations six and seven. It occurs as nodular masses in a carbonate gangue. Each

nodule consists of numerous radiating needles. Thompson has reported manganite associated with limonite and native silver.

NON METALLIC MINERALS.

Of the non metallic minerals which form the gangue, quartz and carbonates are predominant. In most cases quartz is the older but there is evidence to show more than one period of deposition of this mineral. The common carbonates are rhodochrosite (containing some iron) and calcite. Barite has been recorded in association with the pitchblende (Spence 19). Actinolite and chloritic mica have also been observed.

OXIDATION PRODUCTS.

Various oxidation products of pitchblende have been observed. These occur as veinlets and as thin colloidal and crystalline coatings on the pitchblende and associated rocks.

Green nickel stain, probably annabergite, and pink cobalt stain, probably erythrite, are very abundant and widespread.

Hydrated copper carbonates are common and are found near the primary copper minerals. They range in color from

blue (azurite) to green (malachite).

Oxides of iron (limonite) and manganese (psilomelane and wad), as alteration products of an iron manganese carbonate gangue are also common.

More complete consideration of the oxidation products is given later under "A More Detailed Description of Several of the Minerals".

A MORE DETAILED DESCRIPTION

of

SEVERAL OF THE MINERALS.

- - -

URANIUM MINERAL GROUP

- -

PITCHBLENDE.

Pitchblende is an uranate of uranyl and lead containing no thoria or the rare earths. It is the massive and amorphous variety of uraninite and usually contains varying amounts of water. Its composition at the time of deposition was probably U_3O_8.

Five samples of pitchblende ore were polished and examined under the microscope. Of these, four were from the Eldorado property on La Bine Point and one was from the B.E.A.R. property on Contact Lake. (Plate III). The radiographs shown on Plate V were a means of identifying the radioactive nature of the ore. The following etch reactions were noted on the pitchblende: HNO_3 doubtful. HCl negative. KCN negative. $FeCl_3$ tarnishes. KOH negative. $HgCl_2$ negative. Aqua Regia doubtful. Too much faith cannot be put into these reactions since everywhere minute

PLATE IV. INVESTIGATION OF GREAT BEAR LAKE MINERALS

U. of A. 1933

A. Colloform Structure; Pitchblende ore

Mag. 2½ X.

B. Pitchblende Breccia. Fragments are from Original Colloform Structure. Mag. 2½ X.

PLATE IV. INVESTIGATION OF GREAT BEAR LAKE MINERALS

U.of A. 1933

A. Colloform Structure; Pitchblende ore

Mag. 2½ X.

B. Pitchblende Breccia. Fragments are From

Original Colloform Structure. Mag. 2½ X.





veinlets of soluble material interfered with the true reaction.

Under vertically illuminated light the pitchblende appears light grey when in contact with quartz and carbonates, but when in contact with galena, it appears a dark grey. It scratches difficultly with a needle and in polarized light, as would be expected, it is isotropic.

The pitchblende occurs in three forms: (Plate V)

(1) As colloform masses which have been fractured both radially and concentrically. The concentric fractures have all the appearance of shrinkage cracks. It has been suggested that the radial cracks are due to atomic disintegration, but if this is accepted it is difficult to explain the complete filling of these fractures by later minerals. There is also lack of evidence to show different ages for these two sets of fractures.

(2) In a brecciated rock in which, in the hand specimen, the pitchblende fragments appear angular and to bear no relation to each other. Under the microscope, however, each fragment is seen to be a broken-off portion of an original colloform mass. In some cases the fragments are widely scattered; in others they have been only slightly rotated and moved short distances. The radial and concentric cracks are present as in (1).

(3) As curving veins which sometimes traverse the containing rock for considerable distances. This form also shows remnants of colloform structure throughout and again the pitchblende is traversed by numerous radial and concentric cracks which are filled with later metallic and non metallic minerals. In the specimens in which vein-like forms are present there are always the scattered fragments of the no. 2 type which form the brecciated ore. These are shown in Plate VD.

From the above information, it appears that the pitchblende was deposited probably as a colloidal mass, which on drying and hardening formed typical colloform structures, sometime prior to the deposition of the present metallic and non metallic minerals. In the hardening and drying process, cracks (both radial and concentric) were developed. Later minerals were forced in around the pitchblende, breaking it up and scattering its fragments throughout the mass. When the later minerals travelled along the concentric cracks for considerable distances, the vein type of pitchblende was formed. As is later seen, metasomatic replacement was not important in this connection; rather it was a process of open space filling. Such a sequence of events explains the three present forms of pitchblende; the original colloform

PLATE 1. IDENTIFICATION OF GREAT BEAR LAKE MINERALS

U. of A. 1958

4. Coalcomb Hornblende (White), Gangue (Black) Composed Line. Exposed for 40 hrs. Specimen from La Rine Point.

3. Pitchblende Ore (White) Showing Matrix Composed Structures. Exposed for 40 hrs. Pitchblende (White), Gangue (Black) Specimen From "M" Group on Contact Lake.

5. Pitchblende Breccia Pitchblende (White) Gangue (Black) Lode-mal size. Exposed for 48 hrs. Specimen from La Rine Point.

6. Pitchblende (White) Occurring as Veins and as Fragments in a Breccia. Actual Size. Exposed for 60 hrs. Specimen from La Rine Pt.

PLATE V. INVESTIGATION OF GREAT BEAR LAKE MINERALS

U. of A. 1933

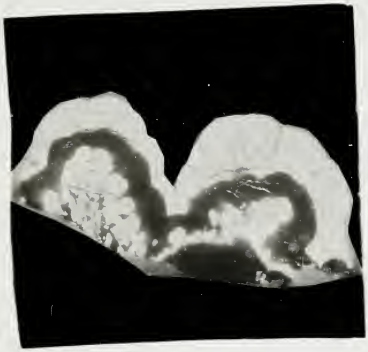
EXPLANATION OF RADIO-GRAPHS

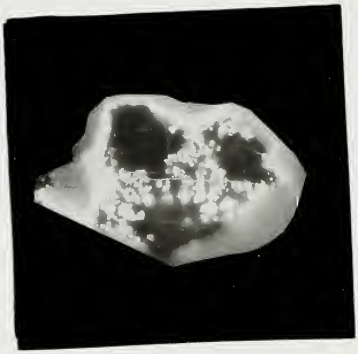
A. Colloform Pitchblende (white), Gangue (black) Actual Size. Exposed for 48 hrs. Specimen from La Bine Point.

B. Pitchblende Ore Showing minute Colloform Structures. Actual Size. Exposed for 40 hrs. Pitchblende (white), Gangue (black) Specimen From "M" Group on Contact Lake.

C. Pitchblende Breccia Pitchblende (white) Gangue (black) Actual size. Exposed for 48 hrs. Specimen from La Bine Point.

D. Pitchblende (white) occurring as Veins and as Fragments in a Breccia. Actual Size. Exposed for 60 hrs. Specimen from La Bine Pt.









masses, the breccia and the "veins".

ASSOCIATED MINERALS.

Minute veinlets of quartz fill the cracks in the pitchblende. These in turn are cut by more prominent veinlets of carbonates. Chalcopyrite in association with a blue mineral (which was in quantities too small to apply tests on, but which is strongly anisotropic and ranges from "blue to fiery red" under crossed nicols and is probably covellite) are seen in isolated masses in the cracks usually elongated along the cracks but sometimes appearing to have attacked the pitchblende walls and to have replaced it to some extent. Evidence of replacement is the very irregular contact between the chalcopyrite and pitchblende. In most cases, however, the chalcopyrite appears to fill the open fractures without replacement. Although there is no evidence to conclude the relative ages of quartz and chalcopyrite it is fairly certain that these two minerals were deposited either (1) simultaneously or (2) the quartz preceding the sulphide. The covellite was probably derived from the chalcopyrite. When quartz and carbonates are both present the chalcopyrite is found with the quartz.

The carbonate gangue traversing the pitchblende gives

tests for the elements manganese, iron, and calcium and it efforvesces freely with cold (1:1) HCl. It is probably the isomorphous series, manganosiderite-manganocalite of the rhombohedral calcite group. Associated with carbonates, small amounts of galena and tetrahedrite were found with covellite. These minerals appear to replace the carbonates. The tetrahedrite also appears later than the galena. These carbonate veins cut through the quartz veinlets. In one specimen a test for barium and the sulphate radical suggests the presence of barite.

OXIDATION PRODUCTS OF PITCHBLENDE.

Many of the pitchblende samples are traversed by minute veins of brightly colored oxidation products of pitchblende. The weathered surface is also often characterized by these products giving bright yellows, reds, and greens. Charles Palache and Harry Berman(20) of Harvard University made an optical examination on several specimens from Great Bear Lake. They report the following minerals.

(a) Mineral X occurring as thin plates of a lemon yellow to yellow brown color, often standing edgewise in drusy coatings on the walls of small vugs in the veinlets. It is accompanied by barite and quartz.

PLATE VI. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933

A. Colloform structures in pitchblende (light) in a quartz gangue.(grey). Black Concentric cracks are filled with later carbonates.80X.

B. High grade silver ore. Silver(white) in a highly weathered gangue(Light grey). 5X.

(b) Uranophane occurring as a green to yellowish green crust, made up of minute needles.

(c) Zippeite occurs in clearly defined tufts, and as a thin crust on uranophane.

(d) Mineral Y occurs in tiny crystalline tufts of a red color and is probably a lead uranium compound. It is probably near curite.

(e) Colloidal substances. These substances vary in color; yellow, red, brown and green. These are probably hydrous uranium compounds, with copper, perhaps, in the case of the green material.

SILVER MINERAL GROUP.

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NATIVE SILVER

Samples of ore containing native silver were studied from La Bine Point, Contact Lake, Glacier Lake and Camsell River.

The following etch reactions and physical properties confirmed the presence of native silver: Color is white. Mineral is isotropic. Soft, and can be readily scratched by a needle with light pressure. HNO_3 efforvesces and stains the mineral dark. HCl a doubtful reaction.

PLATE VII. INVESTIGATION OF GREAT BEAR LAKE, NORTHWEST TERRITORIES.

U. of A. 1933

A. High grade silver ore. Silver associated with cobaltite and niccolite in a calcite gangue. Specimen from Camsell River. 41.

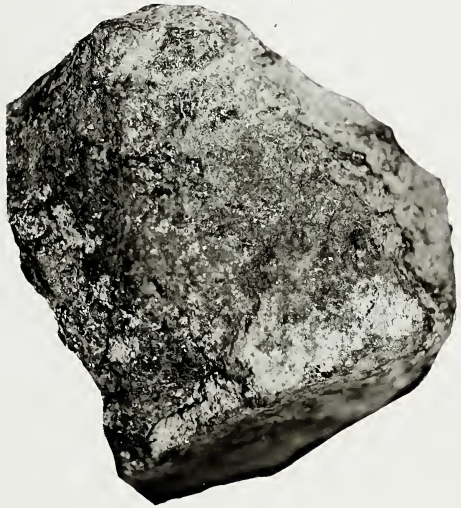
B. Leaf silver in a high grade copper ore which contains chalcocyanite, cuprite, covellite and chalcocite. Leaf silver (white). About natural size.

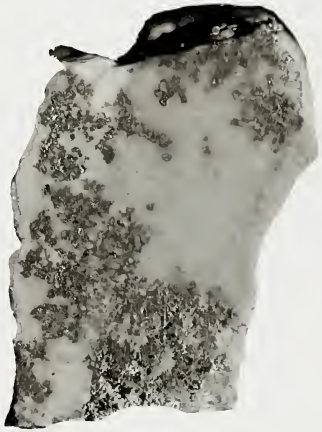
PLATE VII. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933

A. High grade silver ore. Silver associated with cobaltite and niccolite in a calcite gangue. Specimen from Camsell river. 4X.

B. Leaf silver in a high grade copper ore which contains chalcopyrite, bornite, covellite and chalcocite. Leaf silver (white). About actual size.





KCN tarnishes brown. $FeCl_3$ gives irridescent stain immediately. KOH negative. $HgCl_2$ stains differentially brown. It differs in these tests from chalcocite by its color and sectility.

On the polished section the silver occurs most commonly in dendritic and fernlike structures. When in contact with other metallic minerals it commonly occurs as veinlets cutting across them. Sometimes it occurs scattered through the gangue in minute blebs; in other sections larger isolated blebs are common.

ASSOCIATED MINERALS

In the richer silver ores, the gangue consists of carbonates (calcite and rhodochrosite). Rhodochrosite is the more common in specimens from La Bine Point. In specimens from Camsell river the predominant gangue is calcite. Where the silver content is high there is very little other metallic mineralization.

In one specimen from the "AX" property on the Camsell river silver with two hard minerals of the cobalt-nickel group were observed in a calcite gangue. The silver was the more abundant.

One of the hard minerals gave the following reactions:

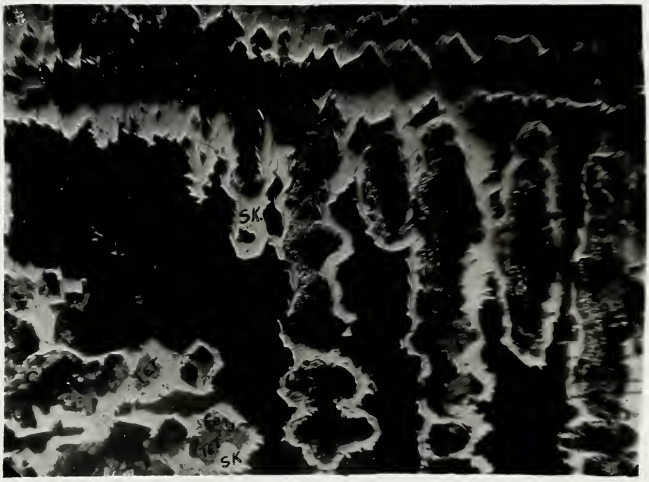
PLATE VIII. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933.

A. Native silver (white) exhibiting dendritic and fern-like structures in a highly weathered gangue (black). Specimen from Glacier Bay. 40 X.

B. Skutterudite exhibiting dendritic structures in a quartz and carbonate gangue. Skutterudite (sk) surrounds tetrahedrite (tet.) and a carbonate(carb.) 22 X.




SK
SK

Anisotropic. Hard. Color, coppery pink. HNO_3 tarnishes immediately with slow effervescence. HCl and KCN negative. $FeCl_3$ slowly tarnishes. KOH negative. $HgCl_2$ stains brown. The mineral apparently is niccolite.

The other hard mineral gave the following reactions: Isotropic. Color almost white(grey). Slightly softer than niccolite. HNO_3 negative. HCl negative. KCN negative. $FeCl_3$ negative. KOH negative. $HgCl_2$ negative. Aqua regia negative. Cubic crystal faces can be observed in some parts. It can be distinguished from braunite by the H_2O_2 reaction which is negative. It differs from chromite in being non-magnetic and by its color. In this way it also differs from magnetite. It differs from hematite in that no red powder is produced on scratching. These tests confirm cobaltite.

The niccolite either was deposited after the cobaltite as suggested by partially replaced cubic structures in the cobaltite or the two minerals were deposited simultaneously.

The silver apparently was deposited later than the cobaltite and niccolite since it traverses them in minute veinlets in several places and also it roughly follows the cubic habit of the cobaltite with an irregular contact suggestive of replacement.

PLATE IX. DESCRIPTION OF PLATE BASE METAL MINERALS.
U. of A. 1953.

A. Natural (unpolish) structure of a cobalt--nickel arsenide mineral, being replaced by native silver.The other remnants are skutterudite(white) and the central zone is native silver (white). The black portions within the cavities are late carbonates. The gangue outside is mostly carbonate with some quartz. 22 X.

B. Same as (A). but magnified 45 diameters.

PLATE IX. INVESTIGATION OF GREAT BEAR LAKE MINERALS.
U. of A. 1933.

A. Original dendritic structure of a cobalt--nickel group mineral, being replaced by native silver.The outer remnants are skutterudite(white) and the central core is native silver (white). The black portions within the dendrites are late carbonates. The gangue outside is mostly carbonate with some guartz. 22 X.

B. Same as (A). but magnified 88 diameters.

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

In a typical high grade specimen from the Echo Bay Group and shown in Plate VI native silver is the only metallic mineral present with the exception of a few inclusions of a soft grey mineral. The grey mineral gives the following reactions: Mineral is grey. Anisotropism doubtful. Under obliquely reflected light mineral is black. HNO_3 negative(doubtful). KCN negative. HCl stains differentially brown. $FeCl_3$ negative. $HgCl_2$ stains dark brown. KOH negative. These reactions cannot be depended upon since the mineral was present in amounts too small to contain the reagents without other minerals being included in the test. This unidentified mineral was found in blebs bordering and also completely surrounded by native silver. Its mode of occurrence suggests argentite.

Where the silver appears as dendrites, there is in several cases, a very thin shell of a hard white isotropic mineral surrounding the silver core. All the standard reagents were applied on this mineral with negative results. It is probably cobaltite, the most chemically resistant mineral of the cobalt-nickel group. Between the silver core and the cobaltite shell is a narrow band of carbonates.

The observations recorded above, point strongly

towards an original "cobalt-nickel" dendritic structure. Silver-carbonate solutions were introduced, and these attacked the central and least resistant mineral first. Successive replacement continued to the outer zones. In this process cobaltite was only partially replaced. The silver-carbonate solutions deposited their burden with a central core of native silver and a narrow carbonate margin within the cobaltite band, the whole retaining the original dendritic structure.

Kidd has reported native silver associated with galena and chalcopyrite (silver later than either) and between botryoidal slabs of pitchblende holding the pitchblende together.

OTHER SILVER MINERALS.

ARGENTITE (Ag_2S) was identified as an inclusion in native silver and in one specimen it occurs with a mineral of which the etch reactions very closely ressemble tetrahedrite. The reactions noted on argentite are as follows: Color grey. Very soft and sectile. HNO_3 doubtful. HCl tarnishes. KCN stains dark. $FeCl_3$ stains darker. KOH negative. $HgCl_2$ stains dark.

With the small amounts of argentite present it does not seem justifiable to consider the large masses of

native silver to be an alteration product of this mineral. Although native silver is not found intimately associated with other metallic minerals in a very great number of cases, nevertheless when it is found as such the relations are strongly suggestive of hypogene origin and not supergene as is held by many for the native silver of Cobalt, Ontario.

PYRARGYRITE (Ag_3SbS_3) is reported by Ellis Thompson as partially replacing tetrahedrite.

COBALT AND NICKEL MINERAL GROUP.

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Arsenides and sulpharsenides of cobalt and nickel have been reported by Kidd(14) and Thompson(18). Their determinations were made on specimens from La Bine Point. Similar minerals were identified by the writer in samples from the B.E.A.R. and Contact Lake Mining companies' properties on Contact Lake and from the "AX" property on the Camsell River. Of particular interest is the mineralization on the Vie claims of the Contact Lake Mining Company. Here, there occurs an ore shoot containing cobalt and nickel minerals and native bismuth as the chief metallics.

PLATE I. MINERALIZATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1939

A. Amsbergite(white) in veins in the wall rock (mottled grey) and in Niocolite(glossy black). The light grey border zones are members of the cobalt-nickel mineral group with inclusions of native bismuth. Dissemination of the cobalt-nickel minerals are seen in the mottled part. About 2 x. Specimen from Contact Lake.

B. Bismuth partially replacing a central cobalt-nickel mineral, surrounded by chloanthite-smaltite. Outer white zone is cobaltite. 10 X.

PLATE X. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933

A. Annabergite(white) in vugs in the wall rock (mottled grey) and in Niccolite(glossy black). The light grey border zones are members of the cobalt-nickel mineral group with inclusions of native bismuth. Disseminations of the cobalt-nickel minerals are seen in the mottled part. About 2 x. Specimen from Contact Lake.

B. Bismuth partially replacing a central cobalt-nickel mineral,surrounded by chloanthite-smaltite. Outer white zone is cobaltite. 16 X.


Co-Ni
Bi
Ag


Bi
Bi
Bi
Co-Ni

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

NICCOLITE, CHLOANTHITE, COBALTITE AND SKUTTERUDITE.

In polished sections studied from the Vie claims on Contact Lake, niccolite, chloanthite-smaltite, cobaltite and skutterudite have been identified in zoned arrangement.

The niccolite forms the central core except in some cases where annabergite is found as a vug lining in the center of the niccolite. The presence of such a vug seems to indicate open space deposition rather than replacement although the latter is suggested by the disseminated nature of these minerals in other parts.

To confirm the presence of niccolite microscopic tests were made and these results follow: Color-coppery pink. Anisotropism very strong. Scratches with difficulty. HNO_3 tarnishes and efforvesces slowly. HCl and KCN negative. $FeCl_3$ stains brown. KOH negative. $HgCl_2$ stains brown.

Surrounding the niccolite are a group of minerals, which under vertically illuminated light and before etching appear as one hard, white isotropic mineral. These were "run down" by using the standard reagents (described in the Appendix of this thesis). Sampling was attempted in order to make microchemical tests but it was not

PLATE II. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of T. 1933

A. Original cobalt-nickel mineral group being replaced by tetrahedrite, a carbonate, and quartz. The tetrahedrite outer boundaries are roughly parallel to the zonal arrangement of the remaining skutterudite(sk). 150 X.

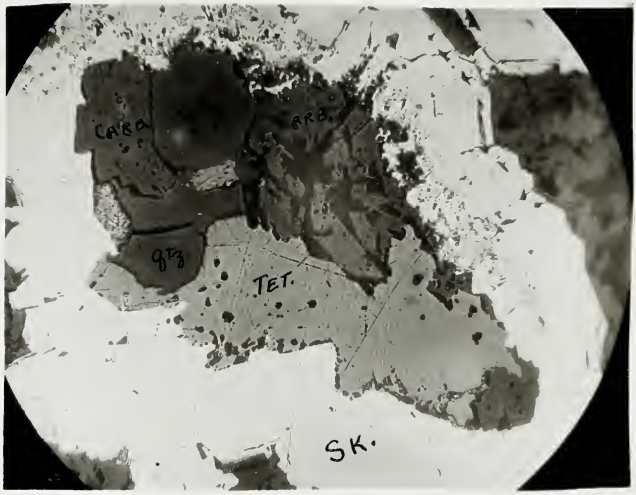
B. Same as (A) but tetrahedrite exhibits remarkable cubic form. 150 X.

PLATE XI. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933

A. Original cobalt-nickel mineral group being replaced by tetrahedrite, a carbonate, and guartz. The tetrahedrite outer boundaries are roughly parallel to the zonal arrangement of the remaining skutterudite(sk).
150 X.

B. Same as (A) but tetrahedrite exhibits remarkable cubic form.
150 X.


CARB.
ARB.
qtz
TET.
SK.


SK.

possible to exclude other similar minerals. Under blow pipe analysis a small sample of this mineral group gave tests for nickel and cobalt. HNO_3 when applied only gave a reaction on the innermost mineral. Confining attention to this zone the following reactions were noted: HNO_3 efforvesces and turns dark. HCl and KCN negative. $FeCl_3$ stains brown. KOH negative. $HgCl_2$ stains differentially. The mineral is hard and isotropic. These tests place the mineral in a group, chloanthite-smaltite($(NiCo)As_2$), corynite(Ni(As,Sb)S), maucherite(Ni_3As_2), and smaltite-chloanthite($(CoNi)As_2$).

Methods as used by Ellis Thompson(x) were next attempted using $FeCl_3$, $KMnO_4$, and aqua regia saturated with FeAsS. The cubic crystal habit, the negative reaction with $KMnO_4$, the positive reaction with $FeCl_3$, the positive reaction with aqua regia saturated with FeAsS, and the presence in vugs, of annabergite are fairly conclusive evidence that the mineral is chloanthite with possibly minor amounts of smaltite in isomorphous mixture.

The specimen was next repolished. Nitric acid was made up in strengths 8:1, 1:1, and concentrated, and these

(x) Thompson, Ellis - Quantitative and Qualitative Determination of Ores of Cobalt, Ontario: Part I. Ec.Geol.Vol.25-1930.

PLATE XII. INVESTIGATION OF CERTAIN BASE LEVEL MINERALS.

U. of A. 1932.

A. Mineral(white) which forms the rich reactions of sphalerite
resembling the less reactive of a cobalt-nickel group
of minerals. Black is a mixture of quartz and carbonate.
80 X.

B. Same as A. 240 X.

PLATE XII. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933.

A. A mineral(white) giving the etch reactions of skutterudite representing the last remnants of a cobalt-nickel group of minerals. Black is a gangue of quartz and carbonate. 80 X.

B. Same as (A). 25 X.

were applied to the white minerals. HNO_3 8:1 negative. HNO_3 1:1 brought out etch structures on the innermost mineral (chloanthite). HNO_3 (concentrated) etched black a marginal mineral leaving a thin band of a hard white mineral unattacked. The marginal mineral according to methods of Ellis Thompson is skutterudite of the formula ($CoAs_3$) as distinguished from Short's skutterudite($CoNiAs_3$). The standard reagents including aqua regia were all applied on the remaining mineral with negative results. As described under native silver this test confirms cobaltite.

Microscopic tests then from the Vie 2 claims show a central vug, lined with annabergite, surrounded respectively in zoned arrangment by niccolite, chloanthite-smaltite, cobaltite and skutterudite.

In a specimen from Glacier Bay, shown in Plate (VIII) and Plate (XI), minerals of this group occur in a zoned arrangement following a rough dendritic structure. Tests were made with the following results: Mineral is grey to white. Isotropic. Hard. HNO_3(1:1) instantly reacts bringing out zonal structure. HNO_3(8:1) negative. HCl negative. KOH negative. $HgCl_2$ negative. KCN negative. $FeCl_3$ slight reaction bringing out some structure. Blow pipe tests for cobalt and nickel proved positive. From Short's determinative tables, the mineral is skutterudite

PLATE XIII. INTERGROWTH OF CUBIC AND LATH HEMATITE.

U. of A. 1934

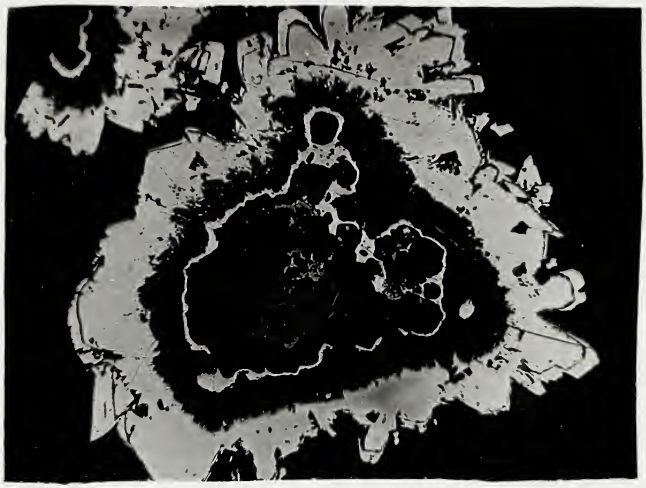
Under crossed
nicols alumel was isotropic. 70 X.
Silver being etched with cone. HNO3.
3. Alumel giving the etch reactions of skutterudite

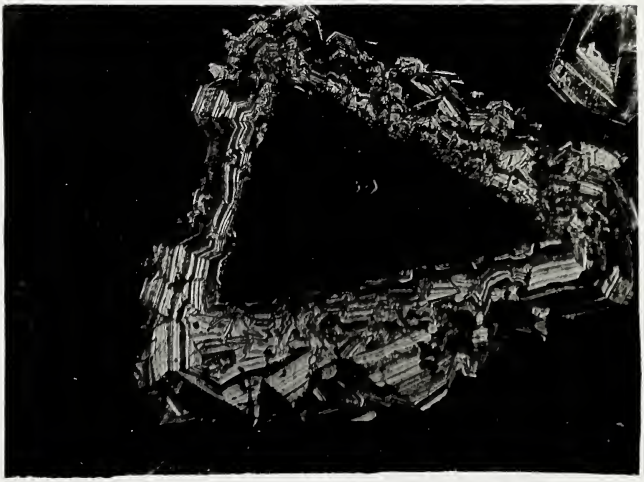
PLATE XIII. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933

A. Tetrahedrite(dark grey) and a carbonate in bands of skutterudite(white). 100 X.

B. Mineral giving the etch reactions of skutterudite after being etched with conc. HNO_3. Under crossed nicols mineral was isotropic. 70 X.





with the formula $(CoNi)As_3$ as compared with the skutterudite identified in the Contact Lake ore in which the formula is $CoAs_3$.

Cobaltite and Niccolite were found in intimate association in specimens from property on the Camsell river. These have been described under "Native Silver".

OTHER COBALT AND NICKEL MINERALS.

RAMMELSBERGITE ($NiAs_2$) was not identified by the writer but is reported by Ellis Thompson as occurring in a massive aggregate of crystals of prismatic habit which are associated with the cubic arsenides, skutterudite, smaltite, and chloanthite. Occasionally also a few isolated crystals of rammelsbergite are found in association with metallic minerals such as pitchblende, chalcopyrite, native silver and tetrahedrite.

SAFFLORITE ($CoAs_2$) was also observed by Thompson in specimens where it is associated in small quantities with rammelsbergite.

ASSOCIATED MINERALS.

Carbonates and quartz are most common as gangue material with this mineral group. In some cases quartz

predominates, in others the carbonates are more important. When native silver is present the gangue is essentially a carbonate. Common carbonates are calcite, rhodochrosite and ankerite.

In many instances, particularly in specimens from the Vie claims, included in the chloanthite, are crystals of a soft, strongly anisotropic pinkish white mineral on which the following etch reactions were noted: HNO_3 effervesces and darkens. HCl stains dark. KCN negative. $FeCl_3$ instantly stains dark. KOH negative. $HgCl_2$ slowly stains differentially brown. The mineral is native bismuth.

The cubic edges and irregular contact in part, suggests replacement by the hexagonal bismuth, it following the cubic pattern of the host mineral chloanthite. The bismuth occurs as an aggregate of variously orientated crystals.

Native silver (Plate IX) was found as a core surrounded by cobalt-nickel minerals which gave test results similar to that described above for skutterudite $(CoNi)As_3$. The skutterudite was apparently the more resistant mineral of an original dendritic and zoned cobalt-nickel group of which the less resistant minerals were replaced by the native silver and its associated carbonate minerals.

OXIDATION PRODUCTS.

An apple green mineral which contains nickel and arsenic was observed as a coating around and near cobalt-nickel minerals. It occurs as a vug lining in niccolite and chloanthite. It probably is annabergite. A rose pink oxidation product probably erythrite is also common and is found associated with the cobalt-nickel group. The color of this mineral varies from almost white to a deep red.

COPPER MINERAL GROUP.

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Of all the metallic minerals determined in the Echo Bay area, the copper minerals are by far the most abundant and widespread. Of these chalcopyrite and bornite are most common. Chalcocite is also abundant. Covellite and tetrahedrite are less common.

BORNITE AND CHALCOPYRITE.

Intergrowths of bornite and chalcopyrite were

observed in several specimens. In one specimen from the Vie claims on Contact Lake, these minerals were found included in tetrahedrite.

The bright yellow of chalcopyrite under vertically illuminated light is fairly conclusive evidence of this mineral. It can be scratched by a needle with light pressure (softer than pyrite). Anisotropism is doubtful. The following etch reactions were observed: HNO_3 doubtful. HCl negative. KCN negative. $FeCl_3$ negative. KOH negative. $HgCl_2$ negative.

The bornite appears a pinkish brown under vertically illuminated light. Under crossed nicols it proves isotropic. Its etch reactions are: HNO_3 efforvesces and stains the surface yellowish brown. HCl negative. KCN stains darker. $FeCl_3$ stains darker. KOH negative. $HgCl_2$ negative. Its hardness is about that of silver. These tests confirm bornite.

The bladed bornite-chalcopyrite intergrowth was the only type observed. In several cases the blades of chalcopyrite begin from the bornite boundary and decrease in width inwards. This condition is somewhat suggestive of replacement by the chalcopyrite. In most other instances, however, isolated blades of chalcopyrite were observed. In one case at least, a blade of chalcopyrite

was discontinued in several places along its length by blue supergene chalcocite which had developed in minute fractures and vugs in the bornite and chalcopyrite. Inclusions of carbonate gangue in the bornite also cut off the blades of chalcopyrite. In all cases the blades are characterized by sharp smooth boundaries and there is no enlargement where the blades intersect. The blades show little relation to crystal boundaries or fractures in the bornite. The chalcopyrite is practically absent outside of the intergrowth. Right-angled intersections of the blades are common.

In view of the chemical similarity of bornite and chalcopyrite and from the above observations, it is fairly evident that the intergrowth represents simultaneous origin for these minerals. Certainly positive evidence of replacement by chalcopyrite is lacking.

Considerable experimental laboratory work has been done on intergrowths of bornite and chalcopyrite by Schwartz(1).

(1)Schwartz, G.M. - Ec.Geol.Vol.26, p.186-1931.

PLATE XIV. IMPREGNATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1938.

A. Fine intergrowth of chalcopyrite(grey) and bornite(dark grey) in tetrahedrite(white). 100 X.

B. Sub-graphic intergrowth of chalcocite(grey) and bornite(white). 100 X.

PLATE XIV. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933.

A. Bladed intergrowth of chalcopyrite(grey) and bornite(dark grey) in tetrahedrite(white). 100 X.

B. Sub-graphic intergrowth of chalcocite(grey) and bornite(white). 100 X.





BORNITE AND CHALCOCITE.

Sub-graphic intergrowths of bornite and chalcocite were observed in specimens from the B.E.A.R. property. The typical association is shown on Plate XIV.

Confirmatory tests for bornite have been given under "Bornite and Chalcopyrite".

Tests giving the following results, confirmed chalcocite: Mineral is isotropic. Color is light blue. Hardness is about that of silver. HNO_3 efforvesces instantly and vigorously. HCl negative. KCN stains dark to black. $FeCl_3$ stains mineral a slightly darker shade of blue. KOH negative. $HgCl_2$ tarnishes slightly.

In all cases where chalcocite was observed, it was of the blue veriety which is generally accepted as of supergene origin. The sub-graphic intergrowth was probably formed at a late stage as the result of the breakdown of bornite. The occurrence of minute veinlets (with irregular walls) of chalcocite, and the chalcocite borders on the bornite are also evidences in favor of supergene origin for the chalcocite.

INVESTIGATION OF GREAT BEAR LAKE MINERALS.

Sulphide intergrowths have occupied the attention of geologists for some time. The interpretations given above are based upon articles by Segall, Whitehead, Ray, Goodchild, Rogers, Newhouse and Schwartz.

Segall, Julius - Ec.Geol.Vol.10, p.462-1915.

Whitehead, W. L. - Ec.Geol.Vol.11, p.1-1916.

Ray, James - Ec.Geol.Vol.11, p.179-1916.

Goodchild, W. H. - Ec.Geol.Vol.11, p.397-1916.

Rogers, Austen F. - Ec.Geol.Vol.11, p.582-1916.

Newhouse, W. H. - Ec.Geol.Vol.21, p.68-1926.

Schwartz, G. M. - Ec.Geol.Vol.22, p.44-1927.

OTHER COPPER MINERALS.

Tetrahedrite was identified in specimens from Glacier Bay and from the Vie claims on Contact Lake.

Under the microscope tests made on tetrahedrite gave the following results: Mineral is isotropic. Color is grey. Can be scratched by a needle with slight pressure. HNO_3 doubtful. HCl negative. KCN negative. $FeCl_3$ negative. KOH negative. $HgCl_2$ negative. These tests confirm either tennantite or tetrahedrite.

Microchemical analysis were next attempted in order to prove the absence or presence of arsenic.

To do this the ammonium-molybdate test of Short(x) was followed. A sample of the mineral was obtained by scratching with a needle and picking up the specks by means of a pointed and wetted match stick. The mineral was transferred to a glass slide and dissolved in HNO_3 1:1. After drying the residue was leached with 1:7 HNO_3 and the new drop transferred to another place on the slide then slowly evaporated. When nearly dry a drop of 1.5% ammonium-molybdate was added. When this dried, 1:7 HNO_3 was added to the residue. The tiny

(x) Short,M.N. - Op.Cit. Appendix p.83.

yellow octahedra of ammonium arsenimolybdate were lacking. The mineral, therefore, is tetrahedrite.

The occurrence of tetrahedrite (from Glacier Lake) is shown on Plate XI. Here it exhibits cubic crystal structure and in places follows the irregular zoned arrangements of the skutterudite in which it is included. In many cases the cubic structure is marked by a definite line (Plate XIB). In others the boundary between skutterudite and tetrahedrite is more irregular. It is fairly evident from these photomicrographs that tetrahedrite was the later formed mineral.

In specimens from the Vie claims on Contact Lake tetrahedrite was found in isolated blebs and as dissiminations in the wall rock. Plate XIV shows inclusions of a bornite-chalcopyrite intergrowth in tetrahedrite. There is a general lack of evidence of age diversity for these three minerals and for this reason they are considered here as of simultaneous origin.

COVELLITE was identified in several specimens. Under crossed nicols it proved anisotropic. Color is a deeper blue(indigo blue) than chalcocite. Its presence was confirmed by the following etch reactions. HNO_3 negative. HCl negative. KCN stains darker. $FeCl_3$ negative. KOH negative. $HgCl_2$ negative.

The covellite was observed in only very small quantities in any one instance. It was observed only in association with bornite, chalcopyrite, chalcocite and possibly tetrahedrite.

OXIDATION PRODUCTS.

The characteristic green and blue oxidation products of the copper minerals are present in many specimens as thin coatings. They are hydrated carbonates and probably range in composition from malachite to azurite.

MANGANESE MINERAL GROUP.

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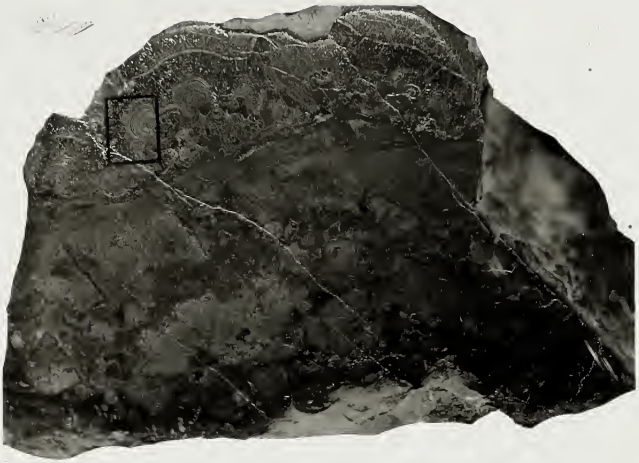
Psilomelane (H_4MNO_5), pyrolusite (MNO_2) and manganite ($MN_2O_3.H_2O$) are the commercially important oxide ores of manganese. These three minerals are so variable in crystal habit and form, and in the quantities of water present, that they are very difficult to distinguish. Geo. A. Thiel(a) describes psilomelane and manganite as exhibiting nodular forms consisting of concentric layers. Pyrolusite is described by E. C. Harder(b) as exhibiting

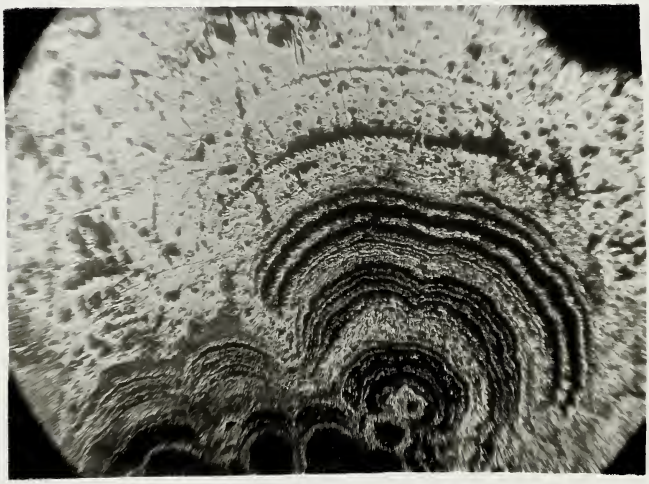
PLATE XV. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933.

A. Polished surface of "nodular" manganite, showing radiating needles and concentric bands. About 2½ X.

B. A portion of (A), showing the concentric parting in greater detail. The bands(black) between the manganite(white) are a gangue of carbonates. 12 X.





specimens from property between Government Survey Stations six and seven (between Dowdell Point and Conjuror Bay).

Sample	No. 1	No. 2	No. 3
Mn	40.37	43.25	46.60
MnO_2	63.88	68.43	73.75
SiO_2	12.70	12.82	13.62
Fe_2O_3	10.06	7.38	5.08

From these partial analysis, basing calculations on manganese present as Mn_2O_3(manganite), sample No. 1 contains 58.0% manganite, sample No. 2 contains 62.2%, and sample No. 3 contains 67.0%.

In the specimens polished one of which was No. 3, no oxides of iron could be identified. Any suspected mettalics gave the characteristic etch tests for manganite. It is, therefore, concluded that the iron and silica are present as partial constituents of the gangue.

The first test applied was the test for anisotropism. As far as could be determined every metallic mineral in these specimens was anistropic. This immediately excluded psilomelane which is essentially amorphous and, therefore, should exhibit isotropism under crossed nicols.

PLATE XVI. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933.

1. Reactive magnetite ore, containing chiefly of hematite. About ½ X.

2. Section-iron (?), showing a felt-like layer very similar to that preserved by Dutel p.55. About 1½ X.

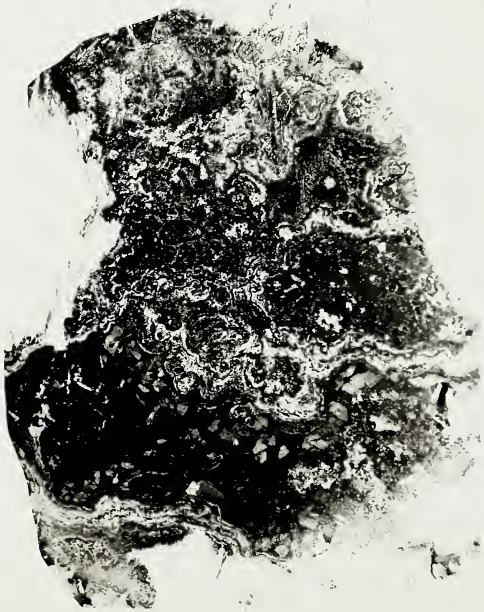
PLATE XVI. INVESTIGATION OF GREAT BEAR LAKE MINERALS.

U. of A. 1933.

A. Massive Manganese ore, consisting chiefly of manganite. About 3 X.

B. Section from (A), showing a felt-like layer very similar to that described by Thiel p.55. About 16 X.





The etch reagents were next applied with the following reactions: HNO_3 fumes tarnish but wash off, otherwise negative. HCl stains darker grey, brings out parallel crystal structure and also shows concentric parting or cleavage. KCN, KOH, $HgCl_2$ and $FeCl_3$ negative. H_2O_2 negative in parts, in other parts very slow efforvescence. These tests confirm manganite.

Throughout the specimens (Plate XV and XVI) these tests were applied on numerous portions with the same results. The mineral differs from pyrolusite in hardness and the H_2O_2 reaction which gives vigorous efforvescence on the latter.

The reagents used by Smitheringale and Thiel were applied with very unsatisfactory results. They use (1)HCl N/6 and concentrated. (2)H_2SO_4 concentrated. (3)H_2O_2(30%). (4)$SnCl_2$ dilute and concentrated. (5) $FeCl_3$ concentrated.

The manganite occurs as nodular masses, the nodules being several centimeters in diameter in some specimens. On the polished surface, under the microscope the mineral shows narrow concentric bands which widen toward the surface. On further examination under crossed nicols these bands are observed to be composed of numerous, variously

oriented, needle-like crystals, arranged in parallel form. The individual needles are discontinued by parting planes which are very irregular but give rise to the concentric structure. Toward the center of the nodules the bands are narrow and are made up of short needles. Toward the outer edge the individual needles are much longer in respect to their width and the concentric parting is less conspicuous.

Thiel describes manganite from the Cuyuna range as occurring in a remarkably similar manner.

"Nodular manganite ore is composed of concentric layers of needle-like crystals of the mineral. The layers vary in thickness from less than a millimeter to several centimeters. Each layer has its own peculiar arrangement of crystals; three different types are common. (1) Layers of varying thickness with individual needles extending across the entire width of the layer. (2) Needles about one-half centimeter in length, with their axes parallel and dove-tailed to build up a layer an inch or more in thickness. (3) Short delicate fibers in an irregular arrangement, forming a felt-like layer. The latter type is generally present as very thin lamellæ between the other two."

OTHER MANGANESE MINERALS.

Psilomelane was observed as an amorphous layer on pitchblende ore from property of the B.E.A.R. Company. Here it is probably a decomposition product of rhodochrosite. It is distinguished from wad by its hardness.

Rhodochrosite is very common and widespread, occurring chiefly with native silver.

ASSOCIATED MINERALS.

The specimens, in which manganite was found to occur, contained no other metallic minerals. For this reason the relation of this mineral to the silver-pitchblende mineralization could not be determined. The non metallic minerals are predominately carbonates, the chief one of which is calcite which often occurs in the center of the nodules of manganite, between the narrow concentric layers. Minute veinlets of a white transparent mineral were seen traversing the specimen. Its negative reaction to all the standard reagents strongly suggests quartz.

SUMMARY OF MINERAL RELATIONSHIPS.

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From a review of the modes of occurrence of the minerals identified and recorded in preceeding paragraphs, it is evident that deposition of the metallic minerals did not occur in a regular and definite sequence. On the contrary there has been considerable over-lapping and probably a number of the minerals were deposited more than once.

From the specimens examined by the writer it is evident that pitchblende was one of the earliest metallic minerals to be deposited. Nowhere is there evidence that it was deposited later than others, but minerals representative of all age diversity (in these deposits) have been found filling the "open" cracks in the pitchblende. If the radial cracks in the pitchblende were formed by radio-active disintegration, the fact that these are completely filled by foreign material would represent tremendous age diversity between the pitchblende and the filling minerals. Nevertheless, disregarding the origin of these cracks, the open space filling by metallic and non metallic minerals, alone, is

evidence of a considerable lapse of time between the deposition of pitchblende and the deposition of the filling material. Other evidences of early deposition for the pitchblende are found where it occurs as breccias and where it occurs as veins.

In spite of these apparently conclusive evidences, Spence(15) shows a radio-graph in which dendritic structure is exhibited, and he points out that pitchblende here is replacing some earlier mineral, possibly silver. The writer sees only two alternatives to explain this reversal of conditions: either (1) the pitchblende is secondary, derived possibly, by some leaching action on earlier pitchblende or (2) the dendrites were not originally silver structures. Pitchblende as amorphous material could not exhibit a primary dendritic structure.

Pitchblende was probably accompanied by quartz with which it was deposited simultaneously. This is suggested by the carbonate filled cracks between the pitchblende and quartz. These cracks follow the colloform structures of the pitchblende and their dimensions are very similar to the interior concentric cracks.

Following the deposition of pitchblende and quartz such minerals as the simple sulphides of iron and copper,

lead, and zinc, and the oxides of iron, along with tetrahedrite and tenantite were deposited with a second quartz gangue. These minerals filled the cracks in the pitchblende and probably broke it up to some extent.

Such minerals as the arsenides and sulpharsenides of cobalt and nickel were next deposited along with carbonates.

Minerals such as native bismuth, argentite, pyrargyrite, covellite and native silver represent a later stage of deposition. Of these native silver was the last. Nowhere is it cut by other minerals but itself is seen cutting several of the later minerals. When found in association with other minerals there is usually definite evidence of replacement or open space filling by the silver.

The relationships of native copper, native gold and manganite were not determined.

A generalized statement of the development of the minerals in the ore bodies of the Echo Bay area may be made as follows:

I Deposition of pitchblende and quartz.

II Consolidation of pitchblende with development of cracks.

III Introduction of a second quartz with the simple sulphides of iron and copper, lead, and zinc, and oxides of iron along with tetrahedrite and tenantite.

IV Deposition of the arsenides and sulpharsenides of cobalt and nickel and one sulpharsenide of lead, and possibly a second tetrahedrite.

V Deposition of native bismuth, argentite, pyrargyrite and covellite.

VI Hypogene replacement and open space filling by native silver.

VII Period of decomposition, resulting in the formation of several alteration products of pitchblende, certain hydrated oxides of iron and manganese, the arsenates of cobalt and nickel and the hydrated carbonates of copper.

OTHER DEPOSITS
with
CERTAIN MINERALOGICAL SIMILARITIES.

- - - -

The minerals of the pitchblende-silver and the silver deposits of Great Bear lake are similar in several respects to those of the complex silver veins of Cobalt, Ontario, the pitchblende-silver veins of Saxony and Czechoslovakia and the pitchblende bearing veins of Cornwall.

SILVER VEINS OF COBALT, ONTARIO.

The silver veins of Cobalt, Ontario are lenticular in shape and they are always found near to the Nipissing diabase sill of Keweenawan age. The veins are found in the diabase, in the Keewatin complex and in the Cobalt series (Huronian). The richer silver ores are confined to the Cobalt series which consists of interbedded breccias, conglomerates and greywackes. The deposits were formed under mesothermal conditions.

The minerals making up the veins are very complex in composition. The more common minerals in order of their abundance are: cobaltite, safflorite, arsenopyrite

silver, skutterudite, rammelsbergite, chalcopyrite, loellingite, niccolite, galena, tetrahedrite, smaltite, gersdorffite, chloanthite, pyrite, pyrrhotite, sphalerite, breithauptite. Of the rarer minerals are: amalgam, native-bismuth, cosalite, dyscrasite, graphite, matildite, millerite, polybasite, proustite, pyrargyrite, stephanite, stromeyerite, timiskamite, ullmannite, zanthoconite.

Ellis Thompson summarizes the development of the vein minerals in the cobalt district as follows:

1. Deposition of the arsenic minerals, along with one sulphide and one antimonide.
2. Deposition of most of the carbonate gangue.
3. Period of fracturing.
4. Deposition of native silver and related silver and bismuth minerals and some later carbonate.
5. Deposition of sulphides of lead, iron, zinc, and copper, and of tetrahedrite, accompanied by a quartz gangue.
6. Last stages of hypogene replacement resulting in development of pyrargyrite, proustite, stephanite, as well as a later silver.
7. Period of decomposition and alteration, forming arsenates of cobalt, nickel, iron, copper, and calcium and carbonates of copper.

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INVESTIGATION OF GREAT BEAR LAKE MINERALS.

THE PITCHBLENDE-BEARING VEINS of SAXONY AND CZECHOSLOVAKIA.

The rocks comprising the Erzgebirge (between Saxony and that part of Czechoslovakia formerly known as Bohemia) are slates, mica schists, hornblende schists and crystalline limestones which are cut by late Palæozoic granite and which in turn is cut by numerous dykes of quartz porphyry and of basalt and phonolite of Tertiary Age. The veins are younger than the quartz porphyry but are older than the basalt and phonolite. The ore bodies are genetically related to the granitic intrusive. The gangue in the veins is mostly brittle clay, quartz, hornstone, calcite and dolomite. The ores in these gangues form stringers, branches and pockets that are very spotty. The ores have been divided into: (Beck d).

1. Silver ores (native silver, argentite, polybasite, stephanite, tetrahedrite, proustite, pyrargyrite,

(a) Ellsworth, H.V. - Rare-Element Minerals of Canada. Ec.Geol.Ser.No.11-G.S.C.

(b) Miller, W.G. and Mickle,G.R. - Rept.Ont. Bureau of Mines, 1905, pt.11,pp.61-63 also Vol.29,pt.11,pp.234-5.

(c) Lindgren, W. - Mineral Deposits.

(d) Beck, - The Nature of Ore Deposits.

sternbergite, argentopyrite, besides rittingerite, acanthite and cerargyrite.

2. Nickel ores (niccolite, chloanthite, millerite).
3. Cobalt ores (smaltite, as well as bismuth, cobaltite, pyrite and asbolate).
4. Bismuth ore (native bismuth, as well as bismuth glance and bismuth ocher).
5. Arsenic ores (native arsenic, arsenopyrite).
6. Uranium ores (pitchblende).

Galena, zinc-blende, pyrite, marcasite, copperpyrite and bornite only occur subordinately and occasionally. Cassiterite occurs near the granite masses.

At Jachymov the cobalt and nickel ores appear to be on the whole the older, the silver ores the younger. The pitchblende is intermediate.

H. Muller summarized a definite succession in deposition of the minerals of the Annaberg, Saxony silver-cobalt veins as follows:

V. Decomposition products such as annabergite and cobalt efforvescence.

IV. Rich silver ores and native arsenic.

III. Calcspar and uranium pitchblende.

II. Brownspar ($MgCO_3$ with some iron) and cobalt-nickel-bismuth ores.

I. Barite, fluorspar and quartz.

I and II together always form the bulk of the filling.

These deposits have at various times produced silver, bismuth, cobalt, nickel and uranium.

THE PITCHBLENDE, TIN AND COPPER VEINS IN CORNWALL.

The rocks in which these veins occur are Devonian slates which have been intruded by large masses of granite of Permo-Carboniferous age.

The most important minerals, from an economic standpoint, are cassiterite, stannite, chalcopyrite and other copper minerals. Native bismuth, sulphides and arsenides of cobalt and nickel, galena, zinc blende, scheelite, etc. occur in minor amounts.

The veins of the deposit at the South Terras Mine have been divided into two classes, (1) those striking east, and (2) those striking north. The veins which strike east are characterized by minerals of high formation temperature. These veins represent the earliest stage of mineralization. The veins running north and south carry minerals of moderate formation temperature such as ores of cobalt, nickel, lead, uranium, and iron. These veins are younger than the east-west veins and they

are divided into (1) those bearing iron and (2) those bearing cobalt, nickel and uranium. In several respects the latter type resemble pitchblende-silver veins of Great Bear lake.

SUMMARY AND CONCLUSIONS.

- - -

1. The minerals comprising the silver-pitchblende and silver ore bodies of Great Bear lake are found in shattered zones of jointing and shearing.
2. The ore bodies occur in altered sedimentary and volcanic rocks, in granodiorite and in diabase, but always near the granitic intrusive contact.
3. There is strong evidence in favor of a genetic relationship between the diabase and the metallic deposits.
4. The minerals comprising the ore bodies represent great variety in composition. Among their elements are antimony, arsenic, bismuth, cobalt, copper, gold, iron, lead, manganese, nickel, sulphur, silver and uranium.

5. The pitchblende occurs in several forms which were originally colloform masses.
6. In the development of the veins, pitchblende was the first metallic mineral deposited; native silver was one of the last.
7. The copper minerals, chalcopyrite, bornite, and covellite are the most abundant. The cobalt-nickel minerals, and native bismuth are very widespread. Pitchblende and silver are locally abundant.
8. In several respects these deposits resemble those of Cobalt, Ontario, those of the Erzegebirge in Saxony and Czechoslovakia, and those of Cornwall, England.
9. According to Dr. A. C. Lane of the National Research Council of the United States (Spence 19) the pitchblende in these deposits is the oldest known. From calculations based on the "lead-ratio" method, it has been estimated that their age is Keewatin, (1280 million years).

Appendix

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A MICROSCOPIC TECHNIQUE FOR THE DETERMINATION OF OPAQUE MINERALS

by

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1933

APPENDIX

on

A MICROSCOPIC TECHNIQUE

for the

DETERMINATION OF OPAQUE MINERALS.

Introduction (x)

HISTORICAL: Although the use of the microscope for the study of rocks dates back many years, it is only within the last decade that rapid advancement has been made in determining the relations and identity of opaque minerals by means of the reflecting microscope.

The microscope was first used in the study of rocks, by Nicol(1) in 1828 and the first practical application was made in 1851 by Sorby(2). Probably the beginning of the study of the polished sections of rock began with Berzeleus(3) in 1814. He examined a section of pyrrhotite megascopically and found another sulphide intergrown in it. In 1863 Sorby examined a polished surface of a piece of iron, thus marking the beginning of the

(x) Much of the following bibliography was borrowed from J. Murdoch.

(1) Sorby, H.C. - Preparation of Transparent Sections of rocks and minerals. Northern Microscopist #2 - 1828.

(2) Sorby, H.C. - Quart. Jour. Geol. Soc.7, 1851.

science of metallography. The method was not applied to the examination of opaque minerals, however, until 1885, when Baumhauer(4) made micro-drawings of the polished section of bornite. E. Hussack(5) in 1904 etched and photographed polished sections of titaniferous magnetite.

In 1900 William Campbell(6) polished and examined, under the microscope, some specimens of pyrrhotite. He was so pleased with the results, that in 1906 he published a paper describing the application of "Metallographic Principles to Opaque Minerals".

In 1908 Campbell and Knight(7) summarized a few characteristics of the Sudbury ore minerals.

Campbell's paper did not stir up any really great interest, however, for several years, although much credit must be given at this time to such men as, C.H. Warren J. Koenigsberger, E.S. Bastin, S. Brunton, F.B. Laney, M. Leo, J.T. Singewald, F.C. Lincoln, L.C. Graton, E.L. Bruce, A.F. Rogers, E.H. Kraus, J.P. Goldsberry, and

(3) Berzelius, J.J. - Gilb.Ann.Vol. 48, 1814, p.209.

(4) Baumhauer, H. - Zeitschr. für Kryst., etc.

(5) Hussak, E. - Ueberdie Mikrostruktur einiger Brasilianischer Titanmagneteisenstein - Neues Jahrb. für Min. etc., Vol. 1, 1904, p.94.

(6) Campbell, W. - The microscopic Examination of Opaque Minerals. Ec.Geol.Vol.1, 1906, p.751.

E.M. Chamot.

In 1911 L.C. Graton(8) and J. Murdoch(9) began a serious investigation of opaque minerals under the microscope at Harvard University. In 1916 J. Murdoch published the results of numerous microchemical tests arranging them in a determinative table, which was by far the most complete work done along this line. In this work Murdoch introduced the name "Mineralography".

In 1917 W.L. Whitehead(10) introduced the name "Mineragraphy", objecting to "Mineralography" since the study embraces only a certain group of minerals.

Following Murdoch's book, work along this line was carried on steadily in the Massachusetts Institute of Technology, Harvard University, Leland Stanford and several other institutions, and numerous papers on oblique mineral study were published in Economic Geology, bulletins of the American Institute of Mining Engineers,

(7) Knight, C.W.- Ec. Geol. Vol.1, 1906, p.767.

(8) Graton, L.C. - Harvard University.

(9) Murdoch, J. - Microscopic Determination of Opaque minerals. John Wiley & Sons, 1916.

(10) Whitehead, W.L. - Notes on the Technique of Mineragraphy. Ec. Geol. Vol.12, No.8, 1917, p.697.

and other magazines.

In 1920, Davy(11) and Farnham(12) published a text-book in which the determinative tables were based upon chemical tests alone. They reduce the reagents, used by Murdoch, to a very few. They use the term "Mineragraphy", of Whitehead.

In 1922 Hans Schneiderhohn published, "Mikrokopischen Bestunmung and Untersuchung von Erzen", in Berlin. In 1925 R.W. Van der Veen published, "Mineragraphy and Ore Deposition", in the Haque.

In 1931, a publication by M.N. Short, "Microscopic Determination of the Ore Minerals" gave students their first complete systematic set of determinative tables. Short's means of identification are based on the following observations:

1. Polarized light - the mineral can be determined as isotropic or anistropic.

2. Hardness - the mineral can be placed in a "soft" or "hard" group depending on its resistance to the scratch of a needle.

3. Etch methods - the methods used by Davy and Farnham are employed.

(11) Davy, Wm.M. and (12) Farnham, C.M.) Microscopic Examination of the Ore Minerals - McGraw-Hill Book Co. Inc. 1920.

4. Chemical tests - a final test is made on a microscopic scale.

Appendix- Microscopic Technique.

A. Preparation of Materials for Investigation.

General Outline

The mineragraphic microscope is a most valuable instrument for identifying opaque minerals and studying their boundary relations. In many larger institutions, very elaborate methods of technique are employed. At the University of Alberta the simplest procedure is followed in the preparation of this study. However, in any institution before the actual identification of minerals can be accomplished there is a number of definite steps in the preparation of the specimen; these are:

1. A highly polished surface must be given to the sample selected.

2. A mounting device, to hold the specimen rigid and level, is necessary.

3. A microscope (petrographic or metallographic) must be transformed to a mineragraphic microscope containing a polarizer, analyzer and vertical illuminator.

4. An artificial source of light is necessary.

5. A suitable means of applying reagents and wash water must be devised.

6. Reagents, made up in proper proportions should be at hand. The number of reagents necessary should be sufficient for the etch tests and likewise the microchemical tests to be employed.

If the results of the study are to be recorded or published it is essential that photographs be taken and this requires the use of a complete photomicrographic equipment.

Methods used at the University of Alberta.

Limitations

The Department of Geology of the University of Alberta has for some years given instruction in petrography, and the Department of Mining Engineering has instructed in metallography. The equipment in each of these departments is fully adequate to meet their demands. However, instruction in the microscopic determination of opaque minerals has thus far been omitted and for this reason the greatest difficulty lies in the limited mechanical equipment available for this study.

Polishing the Specimen.

Polishing the Specimen.

The polishing of any rock specimen is necessarily done in four major operations.

1. The removal of the desired chip from the sample by a diamond disc saw, or chisel.
2. Rough grinding of chip.
3. Fine grinding of chip.
4. The final polishing.

Removal of the Chip.

The sample is first inspected and the desired chip is selected. Its removal is either accomplished by means of a mechanical chisel or a diamond disc saw. For the majority of specimens the mechanical chisel gives a sufficiently flat and accurate surface. However, if the rock has a very conchoidal fracture, or if it is extremely soft the diamond disc is invaluable.

The University of Alberta this year added to its equipment such a diamond disc saw which is very similar to that described by Vanderwilt(1). A copper disc,

(1) Vanderwilt, J.W. - A Simple Diamond Disc Saw. Ec.Geol.Vol.25, p. 222-1930.

which is slightly flanged on its peripheral edge to ensure "free riding", is mounted on a horizontal axis. The diamond dust is supplied by a rotary steel charger while the wheel revolves. The power is supplied by a small electric motor.

The polished chip should not much exceed one square inch in area and its depth should be not greater than one-third of the shortest axis of the required section.

Rough Grinding.

The rough grinding operation is best carried out on a sheet of ground plate glass using as an abrasive for hard and homogeneous specimens, course or medium grained carborundum manufactured by The Carborundum Company, Niagara Falls, N. Y., U. S. A. If the mineral is very heterogeneous in respect to its integral hardness, it is advantageous to reduce the use of coarse abrasives to a minimum and increase the use of finer abrasives since the former tear deep holes in the softer minerals. A good example of this was encountered in polishing a specimen which contained silver and bismuth in a gangue of calcite and quartz. The calcite and bismuth were torn out of the section by medium grained carborumdum.

However, after a new chip was removed by the diamond disc saw and the coarse abrasive operation omitted a very good polish was obtained.

When the selected surface is reduced to one plane and megascopically free of pits the rough grinding operation is complete. If the saw is used to cut the chip two or three minutes should be sufficient for this operation. The specimen is now thoroughly washed and ready for the next step.

Fine Grinding.

The fine grinding is best carried out on a smooth glass plate. Carborundum, number 240 is first used for two or three minutes. The specimen is now observed under the microscope and if the pits and scratches are of uniform size the specimen is washed and ready for a finer abrasive.

Carborundum, number 320 is next used on a smooth glass plate. The direction of motion in this step should be at right angles to the first operation. When the scratches are seen, under the microscope, to traverse in one direction only the operation is complete and the specimen is thoroughly washed.

The time for the complete fine grinding should not exceed ten minutes.

Polishing.

The final step in the preparation of the chip is the polishing operation. This is done on a horizontal steel lap covered with billiard cloth. The metallurgical apparatus used is shown in Plate18A. After the power is applied the wheel is thoroughly soaked with water, then a suspension of levigated aluminum is added. To hasten the operation a counter revolving motion is given the specimen, at all times keeping the billiard cloth wet. After 3 or 4 minutes water alone is added. After 5 minutes the specimen is removed, washed, and dryed by a fan and inspected under the microscope. It should contain no pits or scratches and its relief should be uniform. The time for the complete polishing of an average chip should not exceed 20 minutes.

If the above method is followed, most specimens can be polished successfully, however, in such specimens where water acts as an abrasive, dry grinding is found necessary This may be carried out on carborundum sheets, numbers 1, 0 and 00. The final polish can be secured by using levigated aluminum on a chamois cloth tacked to a block of wood.

A method of polishing THIN sections of ore and rock

is described by Grondijs(1). The advantages lie in the fact that the grain boundaries stand out much more clearly. This method was not attempted by the writer in the preparation of this thesis but it seems pertinent to mention it here.

More elaborate methods than the one outlined above have been described by M. N. Short(2), G. M. Schwartz(3), J. W. Vanderwilt(4), Davy and Farnham(5) and Murdoch(6).

Mounting the Specimen.

Elaborate methods of mounting have been described by Davy and Farnham, and Short. Davy and Farnham mount the specimen by placing it in a lump of modelling wax on a glass slide. The leveling device is a home-made mounting cup made of two-inch pipe fittings.

(1) Grondijs, - Polished Thin Sections of Ore and Rock. Ec.Geol.Vol. 26, p.343-1931.

(2) Short, M.N. - The Preparation of Polished Sections of Ores. Ec.Geol.Vol.21,p.648-1926.

(3) Schwartz, G.M. - Preparation of Polished Sections of Ores. Ec.Geol.Vol.22,p.193-1927.

(4) Vanderwilt, J.W.- Improvements in the Polishing of Ores. Ec.Geol.Vol.23,p.292-1928.

(5) Davy & Farnham - Op. Cit. p.4.

(6) Murdoch, J. - Op. Cit. p.3.

Short recommends a permanent mount, by cementing the polished chip in a section of rectangular brass tubing by means of sealing wax. The number and other designations are stamped on the shorter side of the brass tubing by means of a hammer and dies.

Good specimens of Great Bear lake ore are scarce as yet at the University of Alberta so that the original surface was desired as a museum specimen. For this reason no permanent mounts were made. The simple system of mounting used in the metallurgical laboratory was employed. This consists of a lump of plasticine on a brass slide. The levelling device is a two-inch circular brass tube about three-quarters of a inch long. The specimen is placed face down on a clean sheet of paper within the ring. The plasticine on the slide is then pressed down over the mineral until an even contact is made between the brass circle and slide. Although this system is very handy and simple the specimen so mounted is easily put out of focus in the course of the hardness and etching tests. Plate 17 shows the mineral mounted under the microscope.

The Microscope.

A mineragraphic microscope essentially contains a

Plate XVII. Appendix- Microscopic technique.

V. of I. 1939

Metallographic microscope (A), adjusted
specimen (B), vertical illuminator (C),
and erector (D) across of (Plate E).

PLATE XVII.. APPENDIX- MICROSCOPIC TECHNIQUE.

U. of A. 1933

Metallographic microscope(M), polished specimen(Sp), vertical illuminator(A), and artificial source of light(L).


L
M
A
Sp.

polarizer, an analyzer and a vertical illuminator. Any petrographic microscope can easily be converted into a mineragraphic microscope by simply adding the vertical illuminator between the objective lens and the barrel. A metallographic microscope can be converted by adding a polarizer and an analyser.

The writer uses the metallographic microscope for all physical and chemical tests, but to determine isotropism or anisotropism the vertical illuminator is added to a petrographic instrument.

The simple metallographic microscope with mounted specimen and artificial source of light is shown in Plate17. The instrument is a Bauch and Lomb.

The vertical illuminator (A) is a Wetzlar, manufactured by the E. Leitz Co. and is a prism type. The glass prism occupies approximately one-half of the area of the tube, thus enabling part of the rays reflected from the surface to pass behind the reflector. A more common type of vertical illuminator is the glass disc type described by Short(1).

The 16-millimeter objective is the best all-round lens for mineragraphic work. It gives the most satisfactory field of view and it combines clearness of

(1) Short, M.N. Microscopic Determination of the Opaque Minerals - Int. Dept. U.S.G.S. Bull. 825.

vision with depth of focus. It is also the best lens to use with polarized light.

Artificial Source of Light.

The small lamp box manufactured by E. Leitz Co., N. Y. and shown in Plate 17(L), was found very satisfactory as a source of light. The light which passes through a daylight diffusing glass screen is from an ordinary 15 W-120 Volt. incandescent electric bulb.

Means of Applying Reagents and Wash Water.

The ordinary glass eye-dropper was first used by the writer, for applying reagents. However, since the size of drop could not be regulated this system was dropped and the more simple platinum wire is now used. A small loop is made in the wire and it is bent as shown in fig. (I)

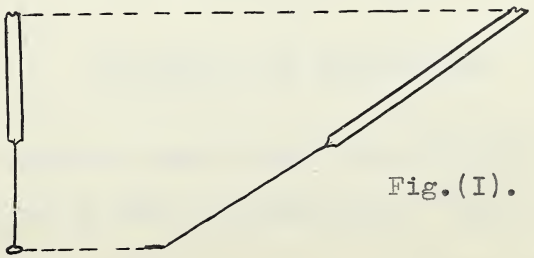


Fig.(I).

(1) Short, M.N. - Op. Cit. p.83.

The loop is dipped into the reagent and then applied to the portion desired. In this way a very small drop can be applied, which is of particular advantage when the mineral particle is very small and associated with other minerals. If the drop covers two or more minerals there is the effect of a small electrolytic cell produced and the true reaction is not observed.

The mineral is at all times viewed under the microscope and any reactions are recorded as they progress.

To wash the specimen, it is kept in place and shot with a fine stream of distilled water from an eye-dropper whose tube has been drawn out to capillary size. The excess water is blown off and the mineral viewed as it drys.

An elaborate method of applying reagents under the microscope has been described by Osborne(1). He uses a pipette placed in a pipette guide which in turn is attached to the lens barrel of the microscope.

Reagents for Etch Tests.

The reagents used by Davy and Farnham and by Short were found to be very satisfactory. These were made up

(1) Osborne, F.F. - Ec.Geol. 26, pp.496-502-1931.

in the following strengths.

HNO_3, 1:1 (1 part HNO_3, specific gravity 1.42, to 1 part H_2O).

HCl, 1:1 (1 part HCl, specific gravity 1.19, to 1 part H_2O).

KCN, 20 per cent solution.

$FeCl_3$, 20 per cent solution.

KOH, 40 per cent solution.

$HgCl_2$, 5 per cent solution.

Aqua regia (3 parts concentrated HCl to 1 part concentrated HNO_3).

H_2O_2, commercial reagent. (3 per cent solution)

Of the above reagents, KCN, $FeCl_3$, KOH, and $HgCl_2$, being dissolved salts, will each leave a residue on evaporation, and this will often form an irridescent scum which may be very easily mistaken for an etch tarnish. The beginner must bear this point in mind, and he must always wash off the reagent before it has evaporated to any extent, otherwise the results have no value whatsoever. Since at least one minute should be allowed for the reaction to take place, the specimen should not be too warm as this will hasten evaporation, also the drop should be high in respect to its width; a flat drop will evaporate too rapidly.

Examples of the reactions of the different reagents

can be seen in Part 1 . of this thesis. The writer followed, where possible, the systematic etching scheme and determinative tables of Short.

After the etch tests are made and the mineral is "pigeonholed" into a small group, chemical tests are made on a microscopic scale. The tests so made by the writer, are described in Part 1 .

Photomicrography of Polished Sections.

Value of Photographs.

Photomicrography of polished sections has by no means gained the prominence it commands. This art was early used successfully in metallography but due to the high costs of having plates made, many publications have lost intrinsic value due to the small number of photographic illustrations present. Davy and Farnham have stated:

> "A well chosen illustration will establish a point more conclusively in the minds of the readers than pages of written description. For the student of ore deposits, such photomicrographs are invaluable records to be preserved as reference material."

Methods and Equipment Used.

In its simplest form, the photographic equipment, consists of a camera box attached to the microscope. This method was employed by Mr. Lowther(1) in photographing transparent thin sections of rock and very good results were obtained.

The writer uses the photographic equipment of the Mining Department which includes a "Leitz" inverted microscope and camera, "Type MM" model 1924. The essential parts of this apparatus can be grouped as follows:

1. Microscope
2. Vertical illuminator
3. Illuminating system
4. Camera
5. Optical bench
6. Table support
7. Optical equipment.

Set up as shown, magnifications varying from fifty diameters to over one thousand diameters can be photographed. By removing the vertical illuminator and using

(1) Lowther, G.K. - Graduate Student of The University of Alberta.

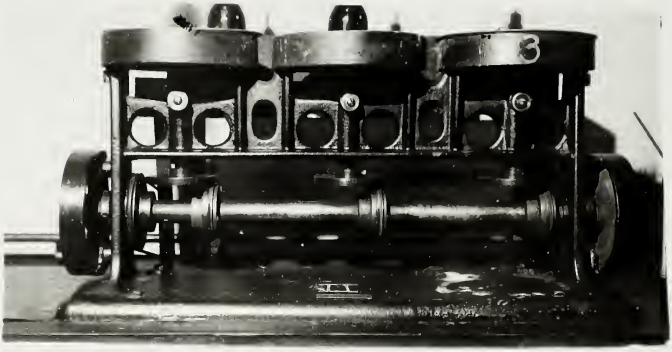
PLATE XVIII. APPENDIX- MICROSCOPIC TECHNIQUE.

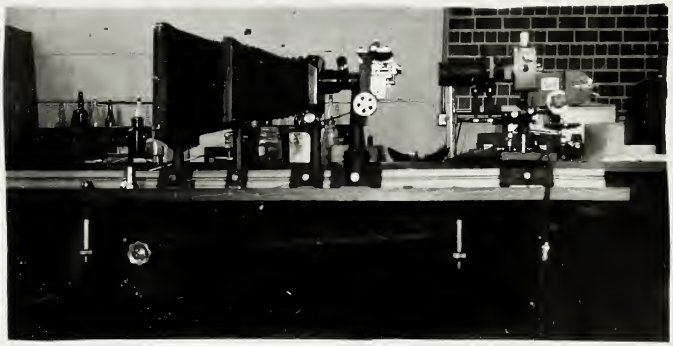
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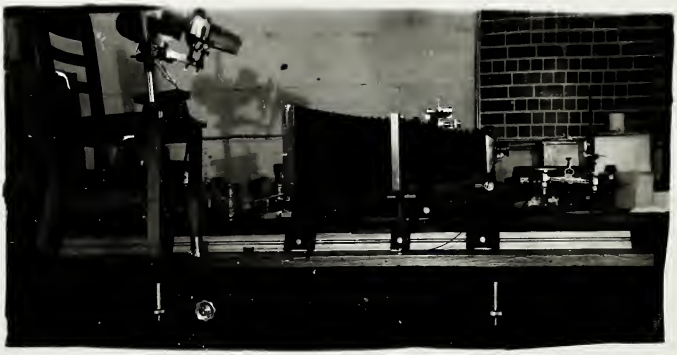
A. Polishing wheels for the final polish.

B. Leitz Microscope and Camera, Model 1924.

C. Camera set-up for macroscopic work.







obliquely reflected light, magnifications from natural size to twenty diameters can be obtained.

Color Filters.

In photographing thin sections the grain boundaries stand out in sufficient contrast in white light so that no light filters are necessary. In photographing thick polished sections, however, light filters are very helpful in emphasizing the contrast and grain boundaries, or on the other hand if there is too much contrast in white light, better results can be obtained by screening out some of the components of white light. Short has ably described the use of a color filter as follows:

> "A color filter is a sheet of colored emulsion between glass plates. When light passes through a green filter, for instance, the colors of the red end of the spectrum are absorbed, but the green, with some of the other colors near it in the spectrum, passes through. To get contrast between two minerals that are close together in the color spectrum, a filter that transmits light at the other end of the spectrum is chosen.

Let us take a specific example. Chalcopyrite is light yellow, and galena silvery white. It is desired to increase the contrast in color between them. If a yellow filter (the K Wratten, for instance) is used, the chalcopyrite reflects yellow light, and its color is not materially changed by light passed through the filter. Galena, being white, reflects a large part of the visible spectrum, including yellow; but only the yellow rays and those near it in wave length reach the eye, as many of the rays at the other end of the spectrum were absorbed by the filter. Hence both chalcopyrite and galena reflect yellow light, and the contrast between them is lessened. It is obvious that a yellow filter is not suitable for bringing out a contrast between two yellow minerals or between a yellow and a white mineral. On the other hand, when a blue filter is used for chalcopyrite and galena, the galena, which reflects most of the colors of the spectrum, will reflect the blue components. The chalcopyrite absorbs colors near the blue end of

the spectrum, and, as only blue rays reach it, the mineral will appear dark. Hence in the photograph the chalcopyrite will be darker than the galena."

EXPOSURE: The time of exposure of the plate varies so widely, depending on the type of filter used, the size of the aperture opening and the distance between the plate and the source of light, that a definite limit cannot be set. However, for average work with the apparatus described above, between 10 and 20 seconds is a common average exposure.

DEVELOPING: The writer uses "Normal" plates which are not sensitive to red light. Of the numerous developers on the market, the writer prefers to use the simple one solution metol-hydroquinone developer which is made up in litre lots. When using, the solution is mixed up 1:1 with water. The solution is made up as follows:

Metol	35 grains	4 gms.
Sodium sulphite	2 oz.	100 gms.
Pot. bromide	50 grains	5.7 gms.
Sod. carbonate	1½ oz.	75 gms.
Water to	20 oz.	1000 c.c.'s.

These are dissolved in the order given.(1)

FIXING: For fixing the plate the simple hypo fixing solution is quite satisfactory. A good formula is as follows:

Sodium thiosulphate (hypo)	300 gms.
Potassium metabisulphite	25 gms.
Water	1000 c.c.'s.

After exposure the plate is developed in a dark room using a dull red lamp. The plate is placed in the developer with the emulsion side up and a gently swaying motion is given the solution. The temperature should be at 68 degrees F. throughout. Five minutes should be sufficient time for developing if the correct exposure is given.

The plate is removed and washed and placed in the hypo bath where it remains until clear. When the solution is thoroughly soaked in hypo the light may be turned on since there is no more developer to react on the emulsion.

The plate, when clear is removed and washed for twenty minutes in running water, after which it is set in a rack and dryed.

PRINTING: The printing is carried out in the dark room. The printing developer used by the writer is the simple

Elon-Hydroquinone solution as given by the Canadian Kodak Co. The solution is made up in the following proportions: (Stock solution formula D-72)

Dissolve in the order named:

Water (about 125 deg. F.)	500 cc.
Elon	3.1 gms.
Sod. sulphite (desiccated)	45 gms.
Hydroquinone	12.2 gms.
Sod. carbonate (desiccated)	67.5 gms.
Pot. bromide	1.9 gms.
Water to make	1 liter

For use take stock solution 1 part and water 2 parts. Develop prints for 45 seconds at 70 deg. F.

To make the plates as shown throughout this thesis the sensitized paper is laid on a flat surface and the negative plates are placed in contact with the paper with the emulsion side down. The "mask" of desired size is then laid over the whole and clamped in place with paper clips. If more than one picture is printed on one sheet, they should be printed separately as each negative will likely require a different exposure. Most plates were found to require an exposure of 10 seconds using a 60 watt electric lamp at a distance of 8 inches.

However, under the same lighting conditions as high as 40 seconds and as low as 3 seconds have been allowed.

Glossy paper is recommended since it brings out more detail than the various matte papers.

After washing in running cold water for twenty min. the glossy paper is removed and ferrotyped. If matte papers are used they can be dried by laying them face down on a flat cloth. A towel serves this purpose very well.

B. Tests On Physical Properties.

Determination of Anisotropism.

Value of the Test.

It is a generally accepted fact that the most useful single test that can be applied in the determination of opaque minerals is the test for anisotropism. This test should be one of the first made since it is the easiest, quickest and most instructive, provided the necessary apparatus is readily available.

Of the earlier workers along this line, J. Koenigsberger, K.Endell, and H.Hanemann are especially important. Among the more recent workers are, F.E. Wright, Edward

Sampson, M. Berek, F. E. Fairbanks and M. N. Short.

In 1919 F. E. Wright published in the Proceedings of the American Philosophical Society a mathematical interpretation of the theory involved. This publication was not available to the writer and was not consulted.

Principles Involved.

The effects observed with polarized light are very ably and briefly stated by Edward Sampson(1) as follows:

> "When polarized light is thrown perpendicularly onto a polished section of a metallic mineral a large part of it is reflected. But before being reflected, this light has penetrated far enough to be affected by the atomic structure of the mineral. In the anisotropic minerals the principal effect of this penetration is to change the direction of the plane of polarization. The reflected light is still essentially plane-polarized, but the plane of polarization is in a different direction from that

(1) Sampson, Edward - Anistropism in Metallic Minerals. Ec.Geol. Vol.24, pp.412-423-1929.

of the incident light. In other words, the plane of polarization of the reflected light has been rotated with respect to that of the incident light. If the analyzer is set at exactly 90 deg. to the polarizer it will not be in a position to cause complete extinction and some light will be seen. With a nearly white mineral, for example manganite, a faint gray will appear when the nicols are crossed, and this may be extinguished completely by rotating the analyzer to correspond with the rotation of the plane of polarization caused by the mineral. When such a colorless anistropic mineral is rotated with the stage it will be found that the plane of polarization is rotated first to the right and then to the left, with an intermediate position of no rotation. A complete rotation of the section under crossed nicols will show four bright positions at which the plane of polarization is rotated and four dark positions in which there is no rotation of the plane of polarization. The greatest amount of rotation caused by any mineral is

probably between 5 and 8 degrees, but a rotation as great as 5 degrees is very uncommon.

Some minerals show colors under crossed nicols which bear no relation to the color of the mineral when seen with the analyzer out. These colors are not to be confused with the interference colors seen in the study of thin sections. Light which was plane-polarized before reflection may show after reflection some elliptical polarization, but the interference color that this would cause is of little effect - probably not more than a faint gray at most.

A few minerals will show in certain sections only two bright and two dark positions when viewed with the tube analyzer crossed. This is due to bi-absorption. The amount of light which is seen with crossed nicols depends on two factors: (a) the amount of rotation of the plane of polarization, and, (b) the amount of light reflected by the mineral. The amount of light reflected depends, in turn, upon the index of refraction and the index of absorption of the mineral. A decrease in either of

these may offset the effect which would otherwise be produced by the rotation of the plane of polarization; and furthermore, if the decrease varies for light of different wave lengths, strong resultant colors will appear. From a combination of these factors, a strong rotation of the plane of polarization may be completely masked. However, if the Wright biquartz wedge plate be used the regular effects are observed; for with this plate actual rotation is the effective agent, not modified by the intensity of the reflected light.

For qualitative work, the most effective test is whether or not, with the nicols crossed or nearly so, the mineral changes intensity of color when the stage is turned. If the intensity changes, the mineral is anisotropic."

Methods of Observation.

There are three ways in which anisotropism may be detected: (1) with the analyzer in the crossed position; (2) with the analyzer slightly rotated from the crossed

position; and (3) by the use of a Wright bi-quartz wedge plate and cap nicol.

1. The test is least sensitive with the analyzer crossed, since on rotation a strongly acting mineral will change from complete darkness to a very faint illumination.

2. "When the analyzer is not in exactly the crossed position, the mineral, when in the four positions of no rotative effect, will be in extinction as if it were isotropic; but when in the four positions of greatest rotative effect, the mineral will be brighter or darker than it would have appeared had the analyzer not been turned, because the mineral by its rotative effect is adding to or subtracting from the effect of the turned analyzer." This method is most outstanding when there is more than one grain in the field of view.

3. A Wright bi-quartz wedge plate gives much the same effect on a single grain as (2) gives on an aggrigate. By this means the amount of rotation of the plane of polarization caused by the mineral can be measured quantitatively.

Methods Used by the Writer.

The second method outlined above is used by the

writer. A small "Wetzlar" polarizer is clamped on the side of the vertical illuminator on a petrographic microscope, such that the light is plane-polarized before it strikes the mineral. Since a strong source of light is absolutely essential for this test, the light from a slide lantern is used. The source of this light is a 400 watt, 116 volt Mazda lamp.

Sources of error in this determination may be listed as follows:

1. Character of the polished mineral surface.

2. The surface of the polished section must be exactly normal to the optical axis of the microscope.

3. Insufficient illumination.

4. Poor adjustment of the nicols.

5. Pseudo-extinctions due to lack of parallelism between polished surface and microscope stage.

6. Irregularities of relief on polished surface.

Hardness.

As an initial determinant, hardness tests have proved most useful in this work. Defining hardness, as the "resistance to the scratch of a sharp instrument" the ordinary steel sewing needle gives excellent results.

Many elaborate schemes of testing hardness have been described, and of particular prominence is the method used by Tolmadge(1).

Tolmadge divides the minerals into seven classes of hardness, using the following standards.

A. Argentite
B. Galena
C. Chalcopyrite
D. Tetrahedrite
E. Niccolite
F. Magnetite
G. Ilmenite

Short includes A B C and D in his "soft" mineral group, and F to G in the "hard" mineral group, Class E, he includes in both groups.

To make the test the needle is held in an inclined position between the thumb and forefinger and dragged, not pushed across the particular mineral in the field of view of the microscope. If, with slight pressure, no scratch is produced, more intense pressure is applied. The weight of the needle alone is sufficient to scratch bismuth, but on the other hand, certain arsenides of nickel and cobalt cannot be scratched at all.

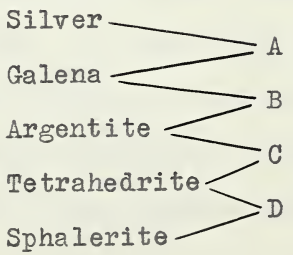
Color.

Although color is a very distinctive property in

(1) Tolmadge, S.B. - Ec.Geol,Vol.20, pp.535-543-1925.

polished opaque minerals, nevertheless it is almost impossible to describe the color of any particular mineral. For the beginner then, the color test cannot be used to full advantage, but with very little practice many of the more common minerals can be determined at a glance by their color. Outstanding examples are pyrrhotite, pyrite, chalcopyrite and galena. Murdoch(1) has stated: "The beginner in this work may at the outset experience some difficulty in this matter of color determination, but it has been found that the ability to distinguish minute differences in color grows very rapidly with experience, and it is astonishing how much more can be seen after a week's start than at the first."

Short suggests that the white and gray minerals be divided into four classes by comparison with native silver, the whitest, and sphalerite, the darkest, of the ore minerals as follows:



(1) Murdoch, J. - Op. Cit. p.72

Chalcopyrite for instance, is darker than galena and lighter than argentite and thus belongs in Class B.

For any such system of color determination, a comparison microscope must be used. The outline given above was only followed in a very general way in this work.

Electrical Conductivity and Polished Surfaces.

Considerable work dating back to 1852 has been done on the electrical conductivity of minerals by European investigators. This early work, however, was confined to macroscopic specimens and only very recently in America have attempts been made to apply such tests to polished surfaces under the microscope.

Among the American workers, Davy and Farnham(1) describe an ideally simple apparatus. It consists of needle terminals attached to holders held in either hand, and connected to a circuit consisting of two dry cells and an ammeter. In 1925 Kerr and Cabeen(2) described a much more elaborate and satisfactory system. The conductivity was determined by the number of electric bulbs lighted by the current after passing through

(1) Davy and Farnham - Op. Cit. p.4.

(2) Kerr and Cabeen - Ec. Geol. 20, p.729-1925.

the mineral, or in certain cases by the amount of deflection which the needle of a milliammeter suffered when placed in the circuit.

Roger D. Harvey(3) in 1928 published a paper describing the work done at Harvard University. He describes in detail elaborate 2 and 4 terminal testers and the method of setting them up for use. The results of some 2000 separate readings which were taken are shown in table form where the resistance in ohms is given for each mineral tested.

No electrical tests were attempted by the writer for the reason that limited time did not permit the accumulation of the necessary apparatus. Short's determinative tables which were followed are fairly complete without this means of identification.

(3) Harvey, Roger D. - Ec.Geol.Vol. 23, p.778-1928.

C. Criteria of Age Relations of Minerals in Polished Sections.

Introductory: For many years practically all descriptions of mineral occurrences have contained a section entitled "Paragenesis". The large number of incorrect interpretations resulting from the study of boundary relations in polished sections induced the National Research Council of U.S.A. in 1931 to appoint a sub-committee on mineral paragenesis. This sub-committee consisting of E. S. Bastin, L. C. Graton, Waldemar Lindgren, W. H. Newhouse, G. M. Schwartz and M. N. Short, published a paper(1) in Economic Geology on "Criteria of Age Relations of Minerals" and although they claim "no note of finality for themselves or for others", they have accumulated here some very valuable information insofar as the determination of age relations of minerals in polished sections is concerned. The subject is discussed in two parts: (1) Simultaneous Deposition, (2) Successive Deposition.
The essence of this paper follows:

(1) Ec.Geol.Vol. 26, No.6, pp. 561-610-1931.

Appendix-Microscopic Technique.

1. Simultaneous Deposition(2)

Simultaneous deposition may be expected under several conditions:

(a) In concentrated aqueous solutions, the addition of a precipitating agent may result in simultaneous precipitation.

(1) If precipitate is crystaline, constituents with stronger power will stand out like phenocrysts.

(2) If precipitate is colloidal, the various compounds will be intimately mixed; may also have phenocrystic texture here.

(b) With rapid cooling the texture may become so fine grained that evidences of overlap are obscure.

(c) In two component melts, the last part will crystallize out simultaneously as a eutectic.

(d) In systems of more than two components, intergrowths resembling the eutectic may form. Familiar examples in pegmatites are the so-called graphic intergrowths of orthoclase and quartz, etc. Some of these

(2) Substances being considered to be simultaneous only if their precipitation from solution begins and ends at the same time.

textures may indicate simultaneous deposition but others probably do not.

(e) Simultaneous deposition may be effected by the unmixing of solid solutions in certain ores formed hydrothermally. There are three main types requiring consideration.

(1) The grating or bladed type. The most outstanding example of this type is the intergrowths of ilmenite and magnetite.

(a) The inclusions of blade, plate, or rod-like forms are characterized by sharp, smooth boundaries. There is no enlargement where the blades join or cross. Replacement veins characteristically enlarge at their intersections.

(b) The included mineral usually shows no relation to mineral boundaries, fractures and certain other features that commonly serve to guide replacing solutions. The inclusions tend to be evenly distributed. A general absence of evidence of replacement in an oriented mineral intergrowth suggests the possibility of exsolution. Any positive evidence of replacement becomes evidence against exsolution.

(c) Commonly the intruded mineral is absent outside of the intergrowths.

(d) The included mineral often forms disconnected units rather than the networks common in replacements along mineral cleavage.

(e) The orientation of the blades, plates, or rods, differs for each grain of the enclosing mineral depending upon the crystal orientation with respect to the plane of the section.

(f) General similarity of the components in chemical and crystal structure is a "priori" indication of the possibility of the minerals forming a solid solution at higher temperatures.

(2) Mottled Type. Microscopic inclusions of one mineral in another have been thought by some to result from exsolution. In other minerals, no doubt the mottled effect is produced by various stages of replacement. Their origin must be judged not from the mottled texture itself but from associated textures.

(3) Graphic Type. (The term "graphic" is here used in a purely textural sense.) The following modes of origin have been suggested:

(a) Simultaneous deposition of two minerals at the eutectic point.

(b) Simultaneous deposition of two minerals but not in eutectic proportions.

(c) Unmixing of a solid solution at the eutectoid point.

(d) Replacement of one mineral by another with little regard to the crystal structure of the host mineral.

(e) Recrystallization during contact metamorphism.

In general in the light of present knowledge it is not possible to diagnose the mode of origin of graphic tectures found in ores from their inherent characteristics but one must rely upon the evidence of associated textures or base their interpretation on geological or geochemical evidences.

II. Successive Deposition.

Deposition in Open Spaces.

(a) Deposition in Pores and Vugs. Deposition in pores is difficult to prove and differentiate from replacement. Deposition in drusy cavities occurs often in ignious rocks and commonly took place shortly after the consolidation by solutions exuding from the rock;

sulphides are not uncommon and may be of slightly diverse ages.

(b) Deposition in Vesicles in Lavas. The filling minerals usually do not crystallize together in allotriomorphic texture, but form definite layers, the first being the oldest.

(c) Deposition in Solution Cavities. Oxidized ores are common in this type, such as limonite, psilomelane, malachite, etc., as stalactitic or colloform deposits. Such deposition may be recognized by one or more of the following features:

(1) Presence of diversely oriented fragments of wall rock that have obviously broken off the walls of a cavity.

(2) Presence of aggregations of cave earth consisting of the relatively insoluble residue from rock - usually limestone - solution.

(3) Directional deposition controlled by gravity - as stalactites (originally vertical) etc.

(4) True crustification paralleling the walls.

(d) Deposition in Open Fractures. The filling will have sharply defined though irregular boundaries. Fracture fillings are commonly characterized by walls that

"match"; i.e., would fit together at least moderately well if the filling were removed. This is often hindered by a certain amount of brecciation.

Replacement.

General Rules for Replacement.

1. "Sulphides", including tellurides, arsenides, etc., replace all rock minerals, all gangue minerals and all "sulphides".

2. Gangue minerals replace rock minerals and other gangue minerals but do not commonly replace "sulphides".

3. High temperature oxides replace all rock and gangue minerals but are rarely replaced by gangue minerals.

4. Oxides rarely replace "sulphides".

5. "Sulphides" may replace rock and gangue in all directions but are commonly guided by fissures and cracks.

6. Replacing gangue metasomes, may develop as metacrysts in rock minerals.

7. Replacing "sulphide" metasomes in the case of some minerals may develop as metacrysts.

8. Higher temperature oxides often develop as metacrysts.

9. Minerals showing idiomorphic forms in sections of replacement ores may be (1) residual crystals, (2) products of local filling, (3) metacrysts.

10. Rounding of crystals in ores does not necessarily indicate replacement, for similar rounding may be shown by phenocrysts and by crystals deposited in open spaces.

11. An initial replacement is not necessarily followed by other replacements.

The criteria that have been used for the recognition of replacement may be listed as follows:

1. Geological or Geochemical evidences.

 Selective Association.

2. Recognition of host structure or texture that has been modified by later guest minerals.

 Psuedomorphism.

 Transection of Structures and Textures.

Selective Association - Some minerals in ores will commonly be replaced more readily than others. In places, therefore, where replacement is in its initial stages the replacing minerals should be found associated exclusively, or at least prevailingly, with one or perhaps

two host minerals.

Pseudomorphism - Features that are on record as preserved pseudomorphically in ores include the following:

Mineral textures and structures - crystal outlines, crystallographic orientation, parting, and cleavage.

Sedimentary textures and structures - bedding, cross bedding, stylolithic structure, form or pattern of grains and oölites.

Textures and structures of igneous rocks - flow lines, form or pattern of grains and porphyritic texture.

Organic structures - form of shells, corals, crinoids, etc., cellular structure of plants.

Transection of Structures and Textures - Although in some cases the structure or textures of the host are preserved through replacement, in others they are obliterated. ...Commonly the minerals that obliterated older structures or textures develop their own characteristic crystal faces.

Localization along Structural or Textural Features that should Serve to Guide the Penetration of Solutions:-

Fractures and other openings - Veinlets are the most common and afford one of the best proofs of age diversity.

Bedding planes.

Schistosity.

Contacts between mineral grains of the same or different species.

Cleavage and parting planes of minerals.

"Islands" in parallel Orientation with other "islands" and with the adjacent "mainland". This condition is not proof of replacement but may result from simultaneous deposition or by deposition in open spaces of the guest on an irregular surface of the host.

Form of the Host-guest Contact - Where the host has approximately non-directional qualities as far as attack by the replacing solutions is concerned, the guest seems usually to develop boundaries that are smoothly concave toward the guest.

On the other hand, where strong directional qualities are apparent in the host, such as bedding, crystals diverse in composition and in orientation, or pronounced cleavage, ...the boundaries are likely to be irregular, sometimes to the point of extreme raggedness.

Outline of Criteria of Hypogene Origin.

The following is an outline of criteria of hypogene origin as given by G. M. Schwartz(1).

Structures and Textures:

x1. Granular texture, intergrown and interlocked grains.

#2. Large grains or crystals.

3. Crushed grains, fragments disarranged, rounded, cemented by gangue and ore minerals.

4. Mutual boundary relations.

x5. Fine intergrowths related to crystallographic directions of one component and not a result of replacement. Ex Solution textures.

x6. Group replacement.

7. Graphic and subgraphic intergrowths.

8. Irregular intricate replacement. Replacement independent of fracturing.

#9. Absence of replaced minerals, relics, fragments or other evidence of replacement.

10. Corroded or rounded relics.

x11. Isometric structure in chalcocite; also shrinkage cracks in chalcocite.

x12. Specular hematite.

13. Diversity in size shape and distribution of a mineral.

Mineralogical and Chemical:

x1. Intergrown ore minerals, one or more of which are normally hypogene.

x2. Ore minerals closely associated with sericite or other hydrothermal minerals.

3. The presence of known hypogene and easily altered minerals near the surface.

x4. Minerals containing elements that part company under supergene conditions.

x5. The presence of an element not present in earlier minerals.

#6. Inclusions in probably hypogene minerals are usually to be considered of same origin.

#7. Same minerals replace host rock and ore minerals.

#8. Lack of known supergene minerals.

x9. Minerals earlier or of same age as mineral known to be hypogene.

#10. Association with minerals not stable under conditions of supergene deposition.

x11. Certain minerals are formed mainly under conditions of high temperature; e.g., pyrrhotite, magnetite, arsenopyrite.

Processes:

#1. Replacement of gangue minerals.

2. Continuous series of replacements or deposition.

#3. Lack of replacement of natural host for supergene replacement or lack of supergene guest mineral.

x Dependable - # Usually but not universally applicable.

Those unmarked are rarely applicable or are not dependable.

Outline of Criteria of Supergene (a) Origin.

Structures and Textures:

#1. Replacement related to fractures, crevices, cleavage, contacts of minerals, network, or anastomosing veinlets.

#2. Narrow rim of replacing mineral around ore minerals or gangue. "Centripetal replacement."

x3. Seriatim replacement. Series of minerals developed from one.

x4. Feathery aggregates or acicular crystals replacing host.

#5. Botryoidal, pisoletic and concentric structures.

x6. Thin coatings of possible supergene minerals on host.

x7. Sooty chalcocite, bluish white chalcocite, etc.

8. Irregular cracks, small grains of chalcocite, "metacolloidal texture."

#9. Serrate boundaries of replacing contacts.

10. Angular relics of older sulphides, especially in earlier stages of replacement by chalcocite.

Mineralogical:

x1. Presence of known supergene minerals (i.e., malachite, melaconite, limonite, earthy hematite, etc.) of same age as late sulphide.

#2. Kaolin when present may under certain conditions suggest supergene origin of ores. Its absence may suggest hypogene origin.

#3. Lack of gangue minerals with sulphides is suggestive.

#4. Abundant chalcocite free from bornite.

5. Presence of selenite in chalcocite - bearing ore.

x6. More readily replaceable mineral most altered, as bornite replaced in preference to chalcopyrite.

7. Presence of quartz in center of veinlets with chalcocite.

Processes:

x1. Selective replacement.

#2. Certain sulphides limited to oxide zone or near it.

#3. Replacement only near porous and somewhat oxidized portions of ore.

(a) The term supergene as used here applies to those minerals deposited by solution that have come from the surface and thus at one time passed into or through the oxidized zone. Artesian circulation would be included except where magmatic contributions have been important.

x Dependable, # Usually,

Those unmarked are rarely applicable, or are not dependable.

Schwartz, G.M. - Ec.Geol.,Vol.27,No.6,P.533 - 1932.

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